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JOURNAL of the STACKS

AIR POLLUTION CONTROL ASSOCIATION

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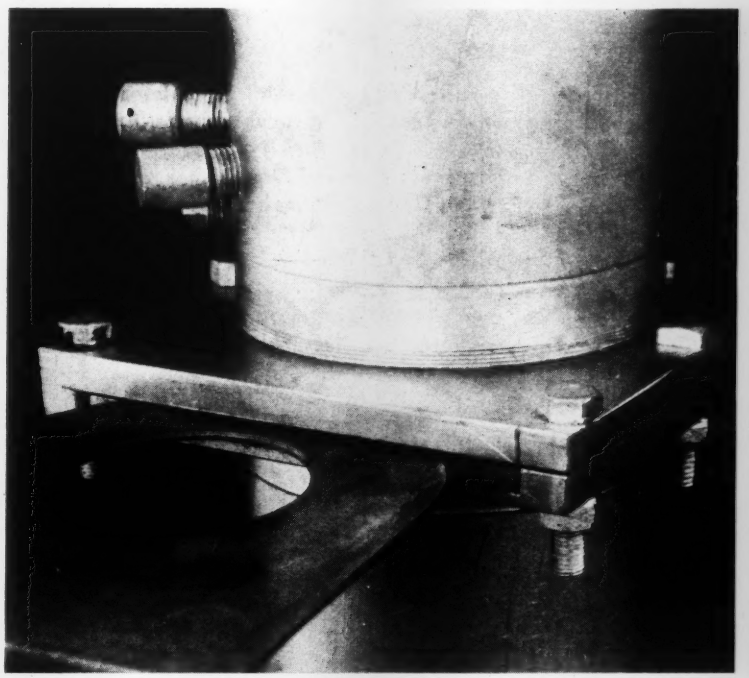
SCIENCE & TECHNOLOGY



Precision Orifice Used for Air Flow Measurement.

(See Page 325)

May 1959
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APPLICATION

Climate Survey

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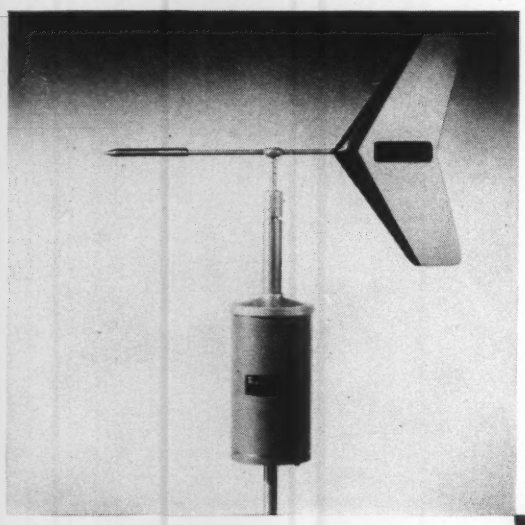

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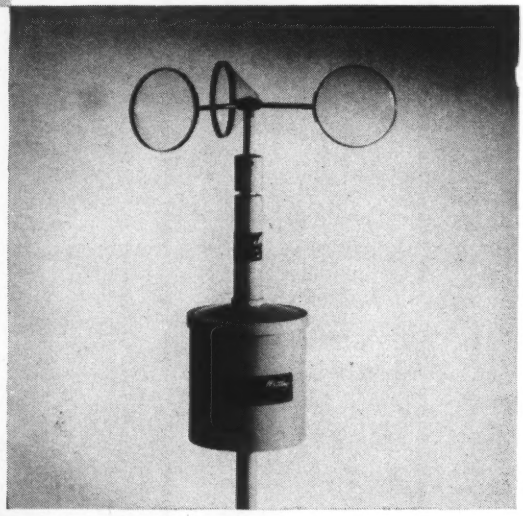

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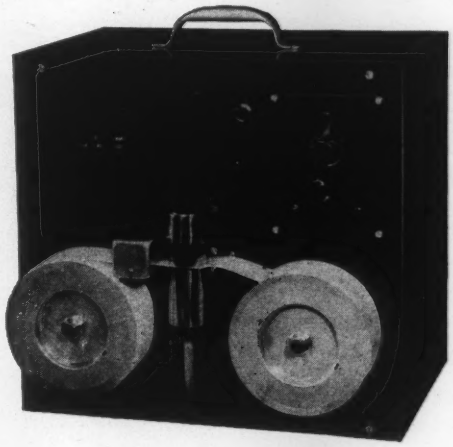

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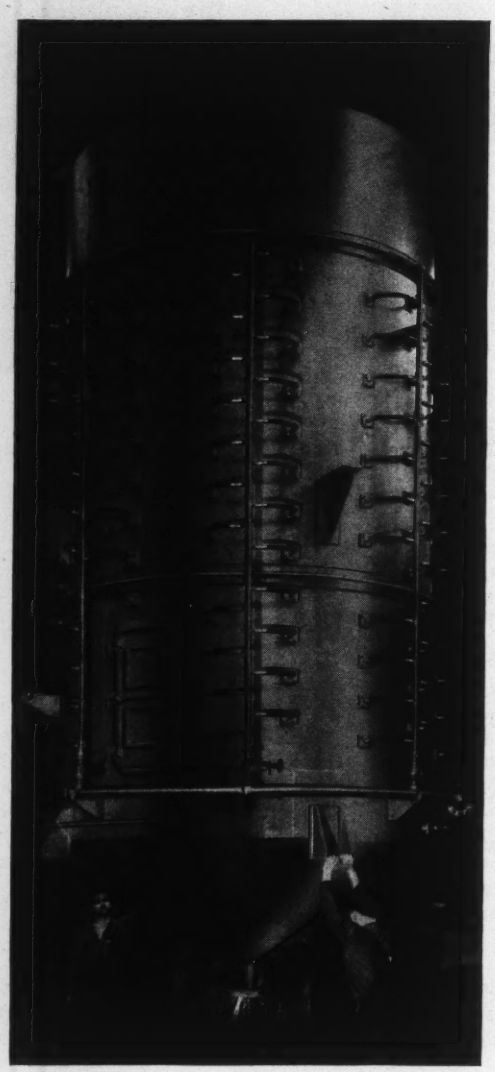

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JOURNAL OF THE AIR POLLUTION CONTROL ASSOCIATION

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Air Purification

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The Editor welcomes writers interested in air pollution problems and encourages them to use the pages of this journal for the expression of their opinions. But neither he nor the Association assumes responsibility for the validity of the opinions expressed herein.

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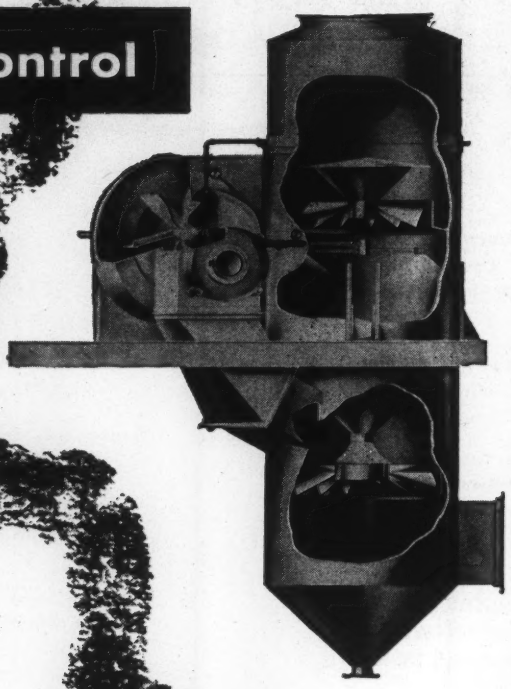
. . . in wet dust control



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An INDEX of AIR POLLUTION and its Relation to Health

NICHOLAS E. MANOS, M. A. Chief Statistician **GAIL F. FISHER, M.A.,** Public Health Analyst, Air Pollution Medical Program, Division of Special Health Services, Public Health Service, Department of Health, Education and Welfare, Washington, D. C.

Introduction

Need for an Index

One approach to the study of possible health effects of air pollution is to investigate the known variations in mortality among metropolitan areas to determine whether or not they relate to the variations in air pollution. This method of study is difficult at the present time because of the inadequacy of data for characterizing air pollution. Air sampling which may eventually provide such information is a comparatively new technique and, as such, has many limitations. As a result, it has been necessary to devise a means of defining the relative amount and kind of air pollution in the metropolitan areas of the United States on the basis of data already available, and to express it as an index of air pollution. The development of this index, its use as a tool in this study, and preliminary results are described in this report.

The Study Population

A useful approach to the study of health effects has been the comparison of the mortality experience in urban areas with that in rural areas. In England, urban-rural differences in bronchitis mortality have been attributed in part to air pollution. Urban-rural differences in lung cancer and heart disease mortality have been demonstrated in this country. In attempting to relate these urban-rural differences to air pollution, basic differences in the study population preclude conclusive findings. For this reason, the present study is restricted to the population groups in 163 metropolitan areas in the United States. This restriction reduces, but by no means eliminates, the problem of differences in the study population.

The mortality data, 1949–51, used in this study are based on the same tabulations prepared from National Office of Vital Statistics data which served as source material for the recently published "Comparative Mortality Among Metropolitan Areas of the United States."[1] Mortality ratios, as described in this publication, have been used in the present study with 2 exceptions: first, the expected number of deaths in each metropolitan area is based on the total population of all metropolitan areas rather than the total U. S. population; and second, whereas the publication was restricted to the presentation of data for white males and white females, several other population groups are included in this study. Those included are as follows:

1. All ages, both sexes, all races
2. All ages, both sexes, white only
3. All ages, male only, white only
4. All ages, female only, white only
5. Ages 0–4, both sexes, white only
6. Ages 5–64, both sexes, white only
7. Ages 65 and over, both sexes, white only

The mortality ratio for any given metropolitan area represents the mortality experience for the indicated population group in that area divided by an expected number of deaths based on the age-specific death rates among all population groups in the combined 163 metropolitan areas.

The Method of Successive Approximations

In this study the term "successive approximations" is used to describe a progressive series of approaches each striving for increased refinement of data and clarification of findings. Whereas the mathematical procedures identified with successive approximations are not used in this study, the concepts basic to this statistical tool are applied.

Mortality ratios for 50 cause of death groups for each of the 7 population groups have been correlated with 30 different indexes of air pollution. The resulting 10,176 simple linear correlations* calculated on high speed computers, serve as a screening device to identify the causes of death that appear to have an association with the indexes of air pollution. This, the first step in a series of successive approximations, has been designed to test many of the ideas and impressions of researchers in the field of environmental health. It was recognized that the volume of correlations produced by this first approximation would include many negative findings. These particular findings, however, serve a purpose in enabling the research worker to proceed with the study of positive findings as they relate to a broad background of information. In other words, the positive finding is no longer an isolated entity.

The information yielded by this initial phase is expected:

1. To supply background information for future steps in the series of approximations
2. To point up problem areas
3. To reveal new areas for research

At best, this procedure could uncover a valid relationship between a particular kind of air pollution and a certain cause of death; in any case, it will yield valuable background information on the geographic variations in mortality as related to environmental factors.

Indexes of the Environment

Kinds of Indexes

Mortality is known to be associated with many environmental factors. Therefore a study restricted to the relationship of mortality and air pollution is not sufficient. If a meaningful association between these 2 variables is ever to be established it must be separated from the relationship of mortality to other city characteristics and socioeconomic factors. Therefore, in the second phase of the study we will use multiple correlations which consider the simultaneous effect of several environ-

* Correlations would have totaled to 10,500 if the selected causes of death had been applicable to all 7 population groups.

Table I—Outline of Selected Indexes

(Indexes in italics were used in first approximation)[1]

I. Indexes based on weighting applied to consensus ranking of 149 manufacturing industries

Matrix A

I_1 - Weights derived from linear curve; developed and used for 3 types of metropolitan areas: Total area, central city portion, noncentral city portion

I_2 - Weights derived from hyperbolic curve; developed and used for 3 types of metropolitan areas

I_3 - Weights derived from S-shaped curve; developed and used for 3 types of metropolitan areas

Matrix B

I_1 - Same as in Matrix A

I_6 - Same as I_1 plus emphasis on industries ranked 16-30, used only in total metropolitan area

I_7 - Same as I_1 plus emphasis on industries ranked 31-45, used only in total metropolitan area

I_{19} - Same as I_1 plus emphasis on industries ranked 46-60, used only in total metropolitan area

Matrix C

I_{14} - Based on industries 1-15 only, equal weighting

I_{15} - Based on industries 1-35 only, equal weighting, used only in central city portion of metropolitan area

I_{16} - Based on industries 1-70 only, equal weighting, used only in central city portion of metropolitan area

Matrix D

I_{17} - Equal weighting of all industries, used only in total metropolitan area

I_8 - Same as I_{17} plus emphasis on industries 1-15

I_9 - Same as I_{17} plus emphasis on industries 16-30, used only in central city portion of metropolitan area

I_{10} - Same as I_{17} plus emphasis on industries 31-45, used only in central city portion of metropolitan area

I_{11} - Same as I_{17} plus emphasis on industries 46-75

I_{12} - Same as I_{17} plus emphasis on industries 76-105

I_{13} - Same as I_{17} plus emphasis on industries 106-149

II. Indexes based on fuel consumption by industries

I_{33} - Coal and coke consumption, by average million tons, used only in central city portion of metropolitan area

I_{37} - Gas consumption, by average, used only in total metropolitan area

I_{41} - All fuel consumption, by average of rank, used only in total metropolitan area

I_{42} - All fuel consumption, weighted by type used only for 2 types of metropolitan areas, total area and central city portion

III. Indexes based on home heating units

I_{63} - Number of home heating units x degree days

I_{64} - Number of home heating units weighted by type of fuel x degree days, used only in total metropolitan area

I_{65} - Number of home heating units weighted by type of fuel

IV. Other Indexes

I_{62} - Percent of employed population engaged in manufacturing, developed and used for 3 types of metropolitan areas

I_{67} - Population density, used only in central city portion of metropolitan area

I_{68} - Population size

I_{70} - Median income

I_{61} - Service station sales, used only for total metropolitan area

I_{58} - Number of production workers for industries 1-35 based on consensus ranking, used only for central city portion of metropolitan area

I_{46} - Weights derived by estimation of SO_2 emission for industries 1-35 based on consensus ranking, used only in central city portion of metropolitan area

1/ In addition to the correlations originally computed in the first approximation, correlations have been computed for the total metropolitan areas, of mortality ratios for five causes of death with the following indexes and are now included in the analysis: I_8, I_9, I_{10}, I_{11}, I_{12}, I_{13}, I_{14}, I_{15}, I_{16}, I_{67}, I_{68}, I_{70}.

mental factors on mortality. Before meaningful combinations of these factors can be outlined, their separate effects must be estimated. Simple linear correlations computed to date include indexes based on:

1. Sources of air pollution
2. City characteristics
3. Socio-economic characteristics

Each index was developed to produce a single figure to characterize each of the 163 metropolitan areas. The source indexes are based on available data related to home heating, non-specific industry, specific industry, and motor vehicle usage. Construction of the specific industry indexes will be discussed later. For home heating 3 separate indexes were developed (Table I, Section III). These were based on the number and type of home heating units, multiplied by a factor for atmospheric temperature to adjust for the amount of usage. The percentage of the employed population engaged in manufacturing was used as a measure of non-specific industry. Usage of motor vehicles was represented by an index based on service station sales. Several indexes of city characteristics and socio-economic factors are available. Population density, population size, and median income have been considered in this first approximation.

Construction of Specific Industry Indexes

Initially it was thought that specific industry groups would be studied in relation to mortality. It was not prac-

Table II—Frequency Distribution of All Correlations Computed

Table II—Frequency Distribution of All Correlations Computed

Cause of Death	Negative Correlations: Greater than.40	Negative Correlations: .25-.39	Negative Correlations: .10-.24	0 to ± .09	Positive Correlations: .10-.24	Positive Correlations: .25-.39	Positive Correlations: Greater than.40	Total	International Code Number
Malignant Neoplasm of Esophagus and Stomach				26	10	124	46	206	150-151
Arteriosclerotic Heart Disease Including Coronary Disease			2	24	56	111	17	210	420
Malignant Neoplasm of Trachea, Bronchus and Lung			1	35	49	107	18	210	162-163
Chronic Endocarditis not Specified as Rheumatic and Other Myocardial Degeneration				27	105	74	4	210	421-422
Chronic Rheumatic Heart Disease			3	50	110	47		210	410-416
Diabetes Mellitus				33	139	21	17	210	260
Malignant Neoplasm of Buccal Cavity			3	68	104	34	1	210	140-144
General Arteriosclerosis			3	158	19	23	3	206	450
Other Diseases peculiar to Early Infancy, and Immaturity Unqualified		44	81	25	7	21	2	180	769-776
Neoplasm of Lymphatic and Hematopoietic Tissues except Hodgkin's Disease		1		46	143	20		210	200, 202-205
Malignant Neoplasm of Pharynx, Nose, Nasal Cavities, Middle Ear, Accessory Sinuses and Larynx				56	136	17	1	210	145-148, 160, 161
Ulcer of Stomach and Duodenum			3	59	135	13		210	540-541
Thyrotoxicosis with or without Goiter				147	22	11		180	252
Pneumonia, except Pneumonia of Newborn		4	47	118	31	10		210	490-493
Hypertension with Heart Disease			17	80	73	10		180	440-443
Congenital Malformations				195	10	5		210	750-759
Vascular Lesions Affecting Central Nervous System			109	88	8	5		210	330-334
Hypertension without mention of Heart Disease			3	188	11	4		206	444-447
Bronchitis and Bronchiectasis		1	28	172	5	4		210	500-502, 526
Tuberculosis with mention of Occupational Disease		2	3	138	34	3		180	001
Malignant Neoplasm of Mediastinum			1	182	24	3		210	164
Malignant Neoplasm of Eye			3	192	12	2	1	210	192
Meningitis, except Meningococcal and Tuberculous			13	156	38	3		210	340
Chronic and Unspecified Nephritis and Other Renal Sclerosis			10	167	30	1	2	210	592-594
Abortion, all other complications of Pregnancy		3	103	37		3		146	640-652, 660, 670-678, 680-689
Pneumoconiosis due to Silica and Silicates		3	4	151	19		3	180	523
Tuberculosis of Respiratory System		12	10	153	33	2		210	002-008
Tuberculosis, Other Forms		1	15	175	17	1	1	210	010-019
Malignant Neoplasm of Bone (Including Jawbone)			4	186	18	2		210	196
Malignant Neoplasm of Lymph nodes, Liver and Thoracic Glands also Malignant Neoplasm of Other and Unspecified sites		5	80	121	2	2		210	156, 165, 198, 199
Hodgkin's Disease			1	95	108	2		206	201
Accidents, Other than Motor Vehicle	4	33	113	53	5	2		210	E800-E802, E840-E962
Malignant Neoplasm of Connective Tissue		1	7	199	2	1		210	197
Rheumatic Fever			5	198	7			210	400-402
Anemias			49	150	11			210	290-293
Malignant Neoplasm of Other Endocrine Glands			2	184	24			210	195
Malignant Neoplasm of Thyroid Gland			5	67	138			210	194
Benign Neoplasm and Neoplasm of Unspecified Nature		1	2	184	23			210	210-239
Asthma		1	138	70	1			210	241
Infections of Newborn		2	65	83				150	763-768
Acute Nephritis, Nephritis with Edema, including Nephrosis		3	128	77	2			210	590-591
Malignant Melanoma and Neoplasm of Skin		6	128	55	17			206	190-191
Suicide	2	5	88	81	4			180	E963, E970-E979
Other Disease of Heart		9	155	45	1			210	430-434
Emphysema without mention of Bronchitis		14	26	170				210	527.1
Acute Poliomyelitis and all other Infective and Parasitic Diseases		14	176	11	9			210	080, 030-039, 040-074, 081-138
Homicide	10	8	125	57	10			210	E964, E980-E985
Symptoms, Senility, and Ill-defined Conditions		19	173	18				210	780-795
Influenza		56	131	20	3			210	480-483
Motor Vehicle Accidents	8	123	49	29	1			210	E810-E835
TOTAL	24	371	2112	5099	1766	688	116	10,176	

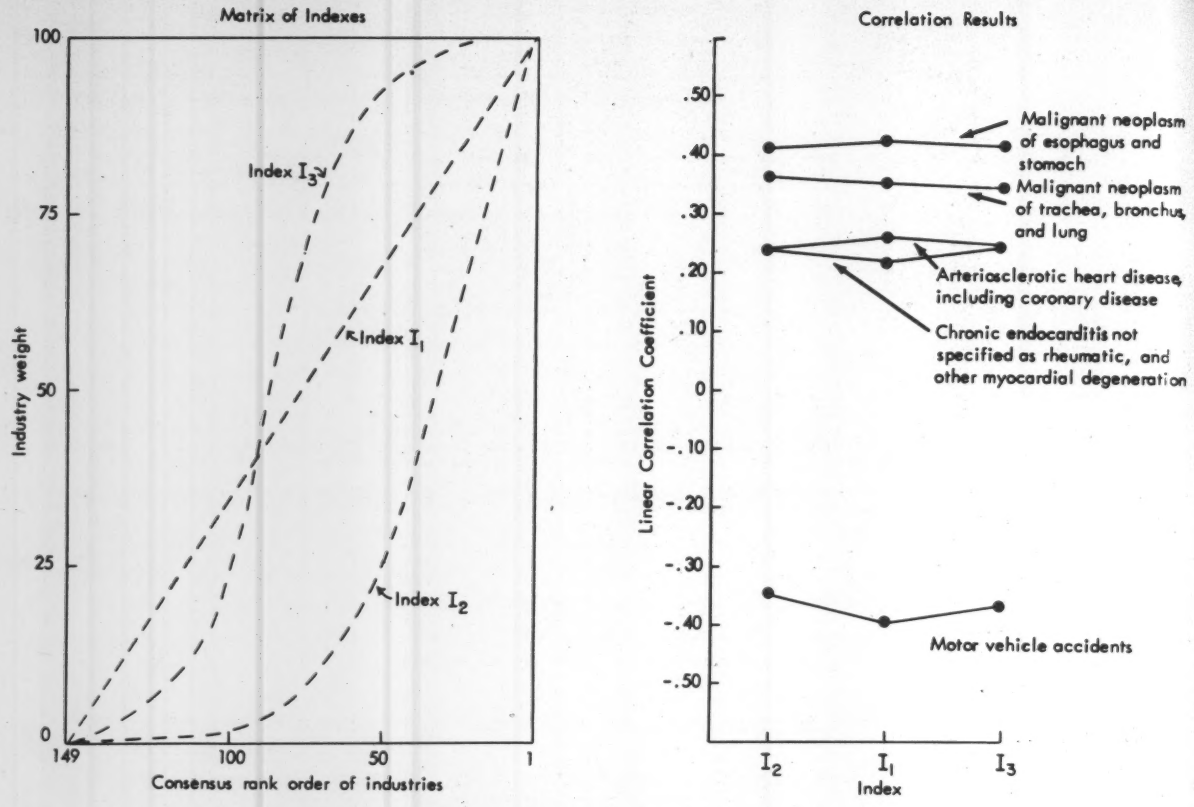

Fig. 1. Index Matrix A and its effect on the pattern of correlation.

tical, however, to conduct the extensive data-collecting project necessary to obtain information on the concentration of a large number of specific industries in each of 163 metropolitan areas. It was determined that the Bureau of the Census could prepare indexes, however, for specific industry groups, since in this way regulations prohibiting the disclosure of data for individual industrial plants would not be violated. The Bureau of the Census then co-operated with the Air Pollution Medical Program in preparing a series of specific industry indexes.

The data used by the Bureau of the Census were taken from the 1947 Census of Manufacturers,[2] and were expressed in terms of number of employees. Since the number of employees in an average-sized plant varies greatly from industry to industry, it was necessary to devise an adjustment factor which would convert numbers of employees to a figure representative of the number of average-sized plants. This factor was developed for each industry by dividing the total number of employees in a specific industry in the United States by the number of plants for that industry.

The development of the specific industry indexes is described in the following paragraphs.

Consensus Ranking

It is known that the amount and kind of air pollution vary with type of industry. Objective measurement of the over-all magnitude of this variation is impossible. As an alternative, a subjective weighting system was developed for the 149 manufacturing industry groups included in the 3-digit code from the Standard Industrial Classification Manual.[3] This weighting system is based on the opinion of 5 persons with experience in the field of industrial hygiene. Each of the persons independently ranked the 149 industries from 1 to 149 in order of their suspicion for possible health effects based on the amount and kind of air pollution that each industry produces. The tendency of each industry to locate near heavily populated areas was also taken into consideration. The 5 rankings were combined into 1 composite ranking. Despite the limitations imposed by the subjective ranking method, it has permitted exploratory research which would have otherwise been impossible at this time.

As an example of the construction of specific industry indexes based on the consensus ranking, the development of I_1 is described. The industries were ranked from 1 to 149 according to the consensus ranking and weights derived from a linear curve were applied so that industry number 1 in the consensus ranking received a weight of 100 and industry number 149 in the consensus ranking received a weight of 1. For each metropolitan area the Bureau of the Census then multiplied these weights by employee data, adjusted to average-sized plants, for each industry, and summed these 149 products to obtain a single figure for each area. The 163 figures obtained from this process provide the index figures for I_1.

Other selected indexes based on the consensus ranking are described briefly in Table I.

Fuel Consumption

Not all of the specific industry indexes were based on the consensus ranking; some are based on the amount and kind of fuel consumed by each of the 149 industries (Table I, Section II). In all, 59 sets of weights were developed for the use of the Bureau of the Census and served as a basis for 59 specific industry indexes, 17 of which were used in the first approximation. These 17 specific industry indexes plus 7 modifications (of these 17) were developed and used for central city and noncentral city portions of the metropolitan areas plus 6 other

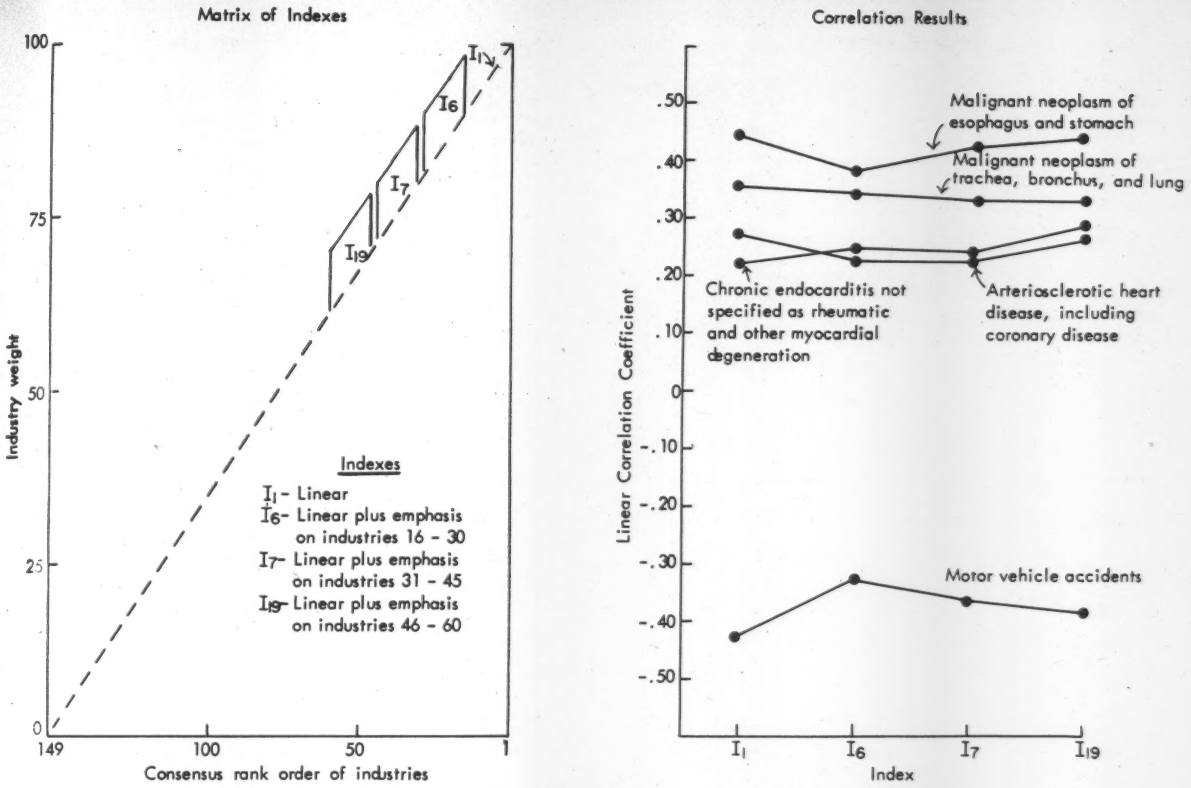

Fig. 2. Index Matrix B and its effect on the pattern of correlation.

selected indexes comprise the 30 included in the first approximation.

A Matrix of Indexes

As seen in Table I many of the indexes were developed from a "matrix." The word matrix is used in the sense of a framework from which an index can originate and take many different forms. The purpose of the matrix is to provide a test for specificity. This test has been designed to rule out the influence of extraneous factors in estimating the association of mortality and industry. The test for specificity of a correlation between an index of air pollution and a given cause of death is made by observing whether a shift in emphasis among the components of the index is reflected in an expected change in the degree of correlation between the variables. We feel that this test is neither necessary nor sufficient for specificity but merely one of several useful tests.

Each matrix developed represents a different method of shifting the relative emphasis given to the various industry groups. I_1 is basic to both Matrix A and Matrix B. In Matrix A of Fig. 1 the weighting for each index is based on a certain type of curve. The hyperbolic curve used in I_2 places increasing emphasis on the top suspect industries and would be expected to yield a higher correlation with mortality than I_1 if the air pollution produced by the top industries is associated with increased mortality. In contrast, I_2 is based on an S-shaped curve which provides less and less differentiation among the top suspect industries and would be expected to yield a lower correlation than I_1.

In Matrix B of Fig. 2, linear weights are used plus emphasis on successive groups in the consensus ranking. It was expected that the correlation would decrease consistently from I_1 to I_{19} if increased mortality were more closely associated with the presence of air pollution from the top suspect industries.

A similar pattern of decrease would be expected for Matrix C of Fig. 3. The basic difference in this matrix is the restriction to selected industries.

Results

The Causes of Death with the Highest Correlations

From the 10176 linear correlation coefficients computed (Table II) the values for the following 5 causes of death included larger numbers of high correlation coefficients than did the remaining 45 causes:

1. Malignant neoplasm of eosphagus and stomach (150–151)
2. Malignant neoplasm of the trachea, bronchus and lung (162–163)
3. Arteriosclerotic heart disease, including coronary disease (420)
4. Chronic endocarditis not specified as rheumatic, and other myocardial degeneration (421–422)
5. Motor vehicle accidents (E810-E835)

The first 4 of these causes of death produced high positive correlations with many of the indexes. Mortality due to motor vehicle accidents produced high negative correlations. It is felt that this negative correlation is brought about by environmental factors other than industrialization which are reflected in the indexes. Such extraneous factors present a problem which is discussed in a later section.

The remaining 45 cause groups did not consistently produce high correlation coefficients. High correlations in these groups more often resulted from association with isolated indexes. Table II summarizes the results of all the correlations.

It must be stressed that the positive correlation coefficients cannot be considered as evidence that air pollution causes death. They merely define an area for further research. A refinement of data, including the application of a variety of critical tests, is necessary before definite associations can be regarded as meaningful (Section D).

Trends in Correlation

Of the 5 causes of death,* only 1,

* Presented in Figs. 1, 2, and 3 for the total white male population group.

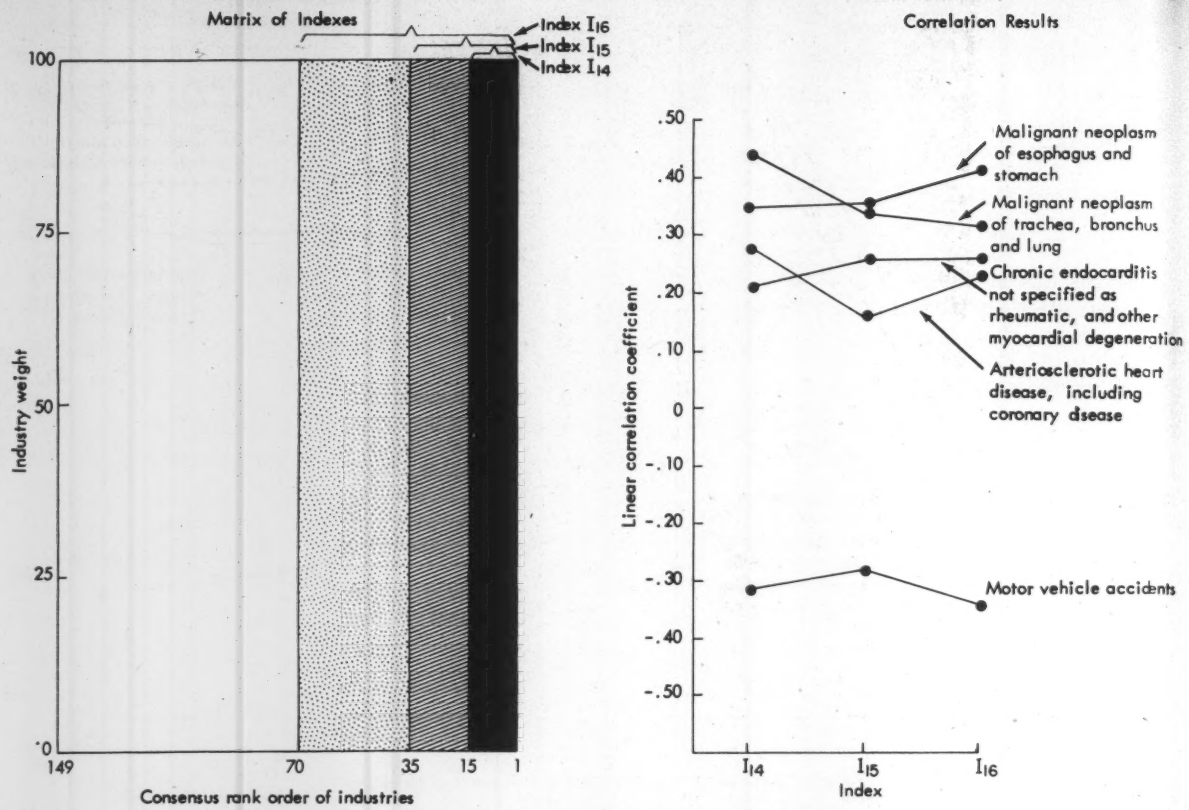

Fig. 3. Index Matrix C and its effect on the pattern of correlation.

malignant neoplasm of trachea, bronchus and lung, demonstrates consistency with an expected correlation pattern as tested by Matrixes A, B, and C (Indexes of the Environment, Part 3). While this pattern is faintly perceptible in Matrixes A and B, it is more clearly defined in Matrix C (Figs. 1, 2, 3). This pattern can be caused by factors other than air pollution and, conversely, it can exist and not be detected because of deficiencies in the method. Nevertheless, the logic of this method justifies its use as one of the many tools of analysis at our disposal.

Extraneous Factors

It is realized that extraneous factors are reflected in the indexes of air pollution. One of the obvious factors is population size. The relationship of 2 of the indexes to population size is shown graphically in Fig. 4. A gradual upward trend in both indexes is noted as population size increases, with a very sharp increase for large metropolitan areas. The extremely sharp increase in the specific industry index, which has been weighted toward suspect industries, reflects the concentration of such industries in highly urbanized areas. Population size is a difficult factor to disentangle from any index of air pollution because it, in part, determines the volume of fuel consumed, the amount of motor vehicle usage, and the location of industry. Techniques for handling this problem are an important part of analysis planned for the future.

Other Results of Present Analysis

Much of the present effort in analysis is being directed to the study of the indexes, per se, for the purpose of selecting those to be included in the next step of the analysis. Many of those devised are being eliminated because analysis indicates that their similarity to other indexes reduces the probability of their contributing new information. Indexes retained for future steps are being intensively studied and refined.

Mortality variations for a number of population groups specific for age-race-sex, including those used in this first approximation, are being investigated. Results of this study will be used in selecting population groups for future analysis. Regional variations for various causes of death and their relationship to variations in the indexes are being studied, but findings are inconclusive at the present time.

Future Analysis

One of the purposes of this study is the delineation of those causes of death with which future analysis by this method should be concerned. An intensive analysis of the 5 causes of death that produced the highest correlations is being continued. It is felt that mortality due to motor vehicle accidents, which produced high negative correlations, must be retained in the analysis because evaluation of the meaning of this inverse relationship and how it affects the interpretation of our results must be made. In addition, other causes of death which have been suspected as being related to air pollution but which did not produce high correlations in this study, will be investigated further. It is recognized that their failure to produce high correlations may have been due to the crudeness of the screening method.

The correlation technique used in this first approximation assumes a linear association between mortality and the various indexes used. Preliminary examination has shown that this may not be true and that experimentation with scale transformation of some of the indexes should be undertaken.

Analysis has pointed up the fact that the age grouping used in the first approximation is inadequate. For example, the separation of the mortality population at age 65 appears to be an unfortunate one. In order to exclude many deaths from ill-defined causes, data for age groups 45–65 and 45–75 are now being prepared for use in the second approximation. Further research on

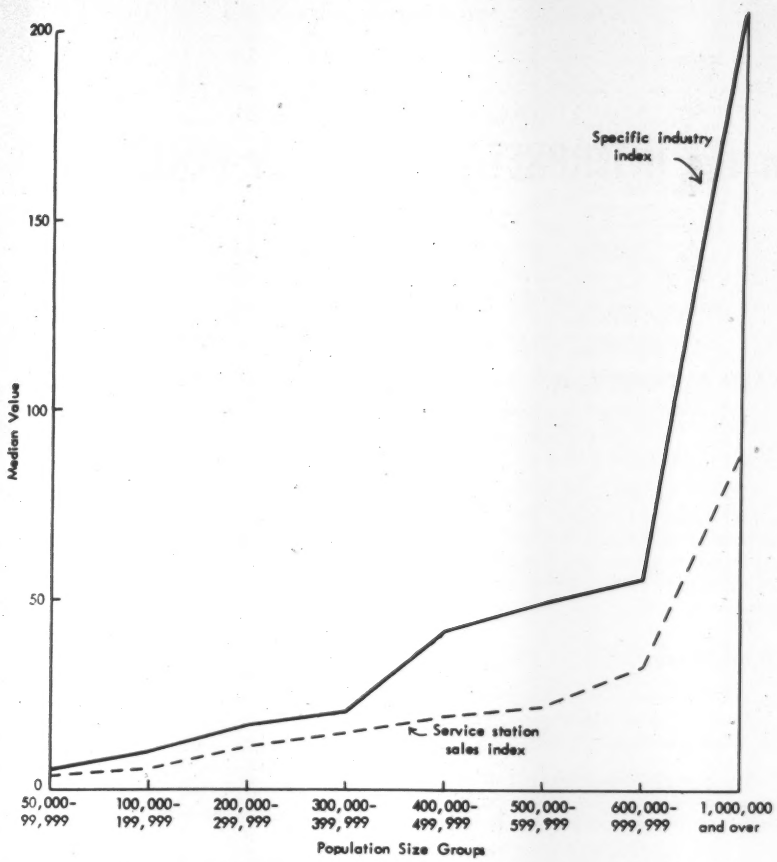

Fig. 4. Trends of major indexes for metropolitan areas grouped by population size.

age variations in cause-specific mortality is being continued.

Forty-five metropolitan areas in the central United States have been selected as a fairly homogeneous group of cities with respect to climate and topography. Multiple correlations of mortality and indexes of environment will be computed for these 45 areas. By this selection it is hoped that the influence of variation in climate and topography will be minimized.

For many diseases, an area with a high mortality rate for males tends to have a high mortality rate for females. An exception to this pattern has been noted in mortality due to malignant neoplasm of trachea, bronchus and lung, where there appears to be little association between the mortality rate of the 2 sexes. This provides an interesting area for research.

Since density of air pollution over an area is influenced by the dispersal power of the atmosphere, this factor will be included in future approximations. Atmospheric dispersal power is related, among other things, to the occurrence of low wind speed and inversion of the atmospheric temperature gradient. The joint effect of these 2 factors on air pollution has not been quantitated for this country. Researchers in England have combined them into a single formula, which is presented in the British Leicester Report.[4] An untested adaptation of this formula has been developed by the United States Weather Bureau[5] and under contract with the Air Pollution Medical Program is being used in the preparation of an index of air pollution potential for 11 cities. We will test this adaptation by applying it to our industrial source indexes for these 11 cities to determine its effect on the correlation of the source indexes with mortality. Since the topography and a real extent of a city are also important factors in the dispersal of air pollution, an attempt will be made to consider these in future refinements of the index of air pollution.

Summary

The cities in this country can be ranked according to an index of air pollution based on general sources of air pollution such as home heating, automobiles, and industry. This has been done in many different ways by shifting the relative emphasis given to the various sources of air pollution. This index, in its various forms, has been correlated with mortality for various causes using several age-sex-race breakdowns. Indexes of socio-economic factors and other city characteristics are also taken into account.

The objective is to determine which forms of the index correlate with mortality. While this approach may be too crude for conclusive findings, it is expected to yield useful background information on the geographic variations in mortality as related to air pollution sources and population characteristics. The findings to date indicate that 4 causes of death produce a large number of high positive correlations with the various indexes of air pollution. These are:

1. Malignant neoplasm of esophagus and stomach
2. Malignant neoplasm of the trachea, broncus and lung
3. Arteriosclerotic heart disease, including coronary disease
4. Chronic endocarditis not specific as rheumatic, and other mycardial degeneration

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Some Considerations in the INTERPRETATION *of Air* POLLUTION *Health* EFFECTS DATA*

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Introduction

Since the days of John Graunt,[1] Thomas Farr,[2] and Lemuel Shattuck[3] epidemiologists have attempted to use death registration data to study disease. The classic work along these lines was that of August Hirsch,[4] whose several volumes on the distribution and geographical pathology of certain diseases was both an attempt to collect international data in a single compendium and an effort to relate geography, climate, and other aspects of man's environment to the causation of disease.

Mortality data have been studied in greater detail than morbidity data, since laws and registration systems have made the former data available and since death is unequivocal. Such data may not be complete; all deaths may not be reported; all illnesses do not result in death (or may not result in death directly, and therefore, may be ignored in reporting); faulty diagnosis may give an erroneous picture of the actual cause of death; and other factors such as treatment, surgical skill, and the patient's susceptibility or resistance may change the pattern of reported death.

Nevertheless, for studies involving comparisons of certain health effects throughout a nation (or any large geographic area), mortality statistics are the only ones available in standardized and recognized form. A study of the distribution of cancer is an example. It concerns the distribution of deaths in a population and attempts to characterize the environment in order to find associated factors or processes to which subsequent controls may be applied to prevent illness. Such a study may embody both measurements involving the distribution of agents and measurements attempting to characterize the environment to which the population is exposed. In air pollution studies this latter approach cannot easily be used since the suspected toxic and chemical agents are still unknown or difficult to assess quantitatively.

Hypotheses

The approach discussed by Mr. Manos[5] in the preceding paper was based on the following hypotheses:

1. The distribution of deaths from certain causes in a population may be geographically determined and may be related to the distribution of air pollutants in the community.
2. An index based on data concerning industry, automobiles, and domestic fuel-use could be prepared and would represent air pollution within certain geographic areas.

In other words death could be used as an index of health effects resulting from air pollution in a community, and air pollution could be reflected in economic and industrial data.

Several points must be kept in mind. First, this measure of air pollution may not adequately represent the specific contributions of all sources. Secondly, this computation fixes an average figure for a city, whereas air pollution may vary daily, often from extremely low levels to very high ones in a matter of minutes or hours, and it may be that only these peaks or "bursts" have biological effectiveness on the human being. Third, as stated above, air pollution under these conditions may not cause death but only defect and disability, which may go unrecognized or unreported in the general population.

Finally, deaths registered in the year 1950 may be the result of air pollution experienced by the population 20 years earlier, which has had a delayed effect. Delayed death is very difficult to measure as a statistical association. A complicating factor here is the mobility of

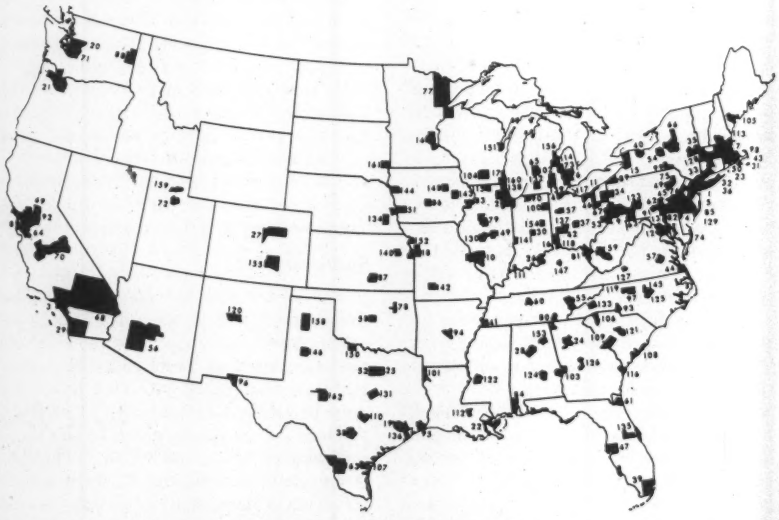

Fig. 1. Location map of the 163 metropolitan areas.

* Presented at 51st Annual Meeting of APCA, May 25–29, 1958, at Philadelphia.

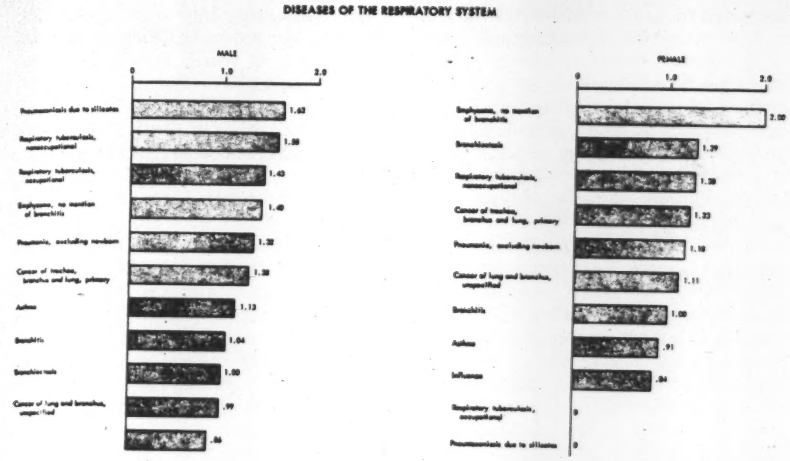

Fig. 2. Ratios of age-adjusted mortality rates of central city counties to non-central-city counties in the United States, 102 causes, white population, by sex, 1949–51.

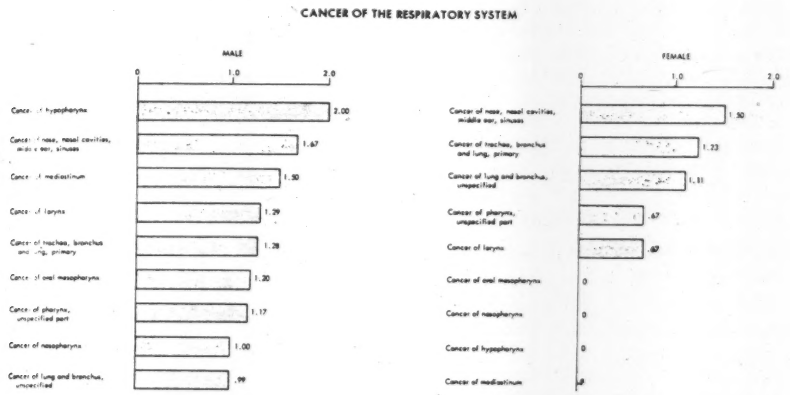

Fig. 3. Ratios of age-adjusted mortality rates of central city counties to non-central city counties in the United States, 102 causes, white population, by sex, 1949–51.

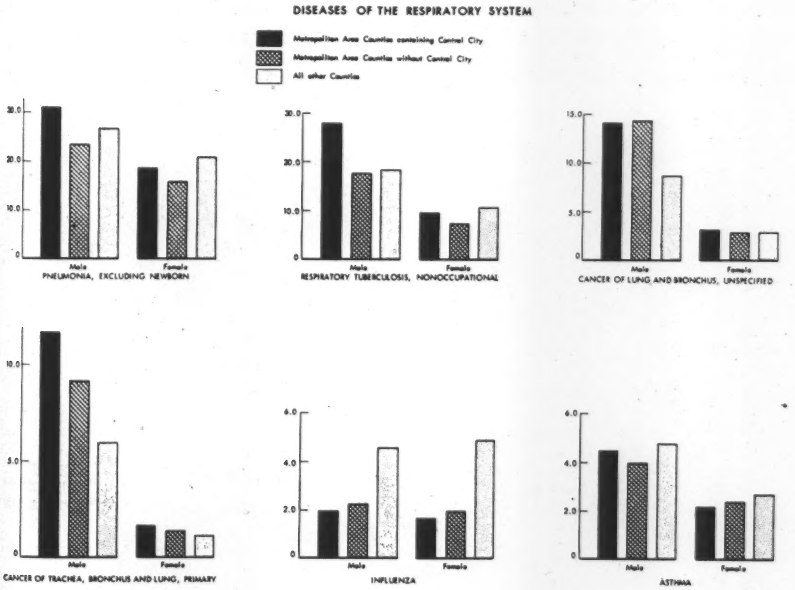

Fig. 4. Age-adjusted mortality rates by degree of urbanization in the United States, 102 causes, white population, by sex, 1949–51.

the population, for, although a person may have been exposed 20 years earlier in City A, he may well die in City B, which does not have a significant level of air pollution. Only 29.5% of the people now resident in the state of Nevada were born there; in California 63.1% of the population has come from elsewhere; and in only a few states—such as Mississippi, Alabama, and Pennsylvania—has any significant proportion of the population remained within the state since birth.[6] Even migration within the state may complicate the pattern of mortality distribution.

Findings

Fig. 1 shows the location of 163 metropolitan areas in the United States, from which mortality data were collected. This is based on data for the period 1949–1951, provided by the National Office of Vital Statistics. Mortality, by place of residence, for geographic area has been collected for 102 causes of death. Tabulations were prepared by age, sex, racial groups, and by degree of urbanization, for each of the 163 metropolitan areas.[7]

The Bureau of the Census defines a Standard Metropolitan Area as a county or group of contiguous counties containing at least one city of 50,000 or more inhabitants. Other contiguous counties, essentially metropolitan in character, and socially and economically integrated with the central city, are included in 45 of the 163 areas represented on the map.

Data collected from these areas for these causes of death were tabulated by age-sex-race, and expressed as a ratio of observed deaths divided by expected deaths, based on the mortality experience from that cause for the entire United States population.

The distribution of metropolitan areas in the United States is obviously not uniform; there are several such areas in New England and the northeastern section, while some western States have no metropolitan areas. Metropolitan areas, do, however, represent reasonably well the geographic distribution of the United States population.

Fig. 2 shows some typical findings among diseases of the respiratory system. Pneumoconiosis due to silicates is 1.62 times as frequent among males in central city counties as in non-central city counties. Influenza on the other hand, is more frequent in the non-central city counties.

In Fig. 3, Cancer of the Respiratory System, various cancers of specific sites are shown in similar ratios. Cancer of the nasopharynx and cancer of the lung and bronchus in males are the only 2 sites of the 9 represented in which urban-nonurban differences are not large;

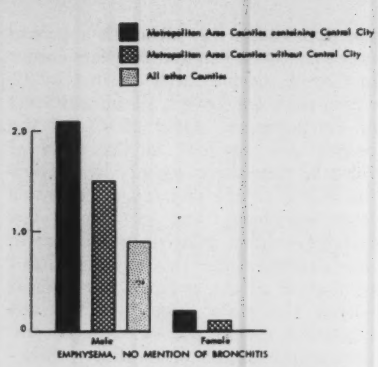

Fig. 5. Age-adjusted mortality rates by degree of urbanization in the United States.

among females, however, cancer of the pharynx (unspecified part) and cancer of the larynx are both more frequent in the non-central city counties than in the central area.

In Fig. 4 several diseases of the respiratory system are represented by age-adjusted mortality rates by degree of urbanization in the United States. One may readily observe that cancer of the trachea, bronchus, and lung in males increases as one proceeds from the less urbanized areas to non-central city areas to the central city. The same appears to be true for the female in a much diminished way. In contradistinction the mortality rates of influenza are higher in the nonurban areas and descend centrifugally. In Fig. 5 one sees that emphysema rates, although much lower, ascend in the same relative order of magnitude as cancer of the trachea, bronchus, and lung.

In reviewing the data for all cancer types studied, only cancer of the liver (unspecified), cancer of the small intestine (including duodenum), cancer of the skin other than malignant melanoma, cancer of the lip, cancer of the eye, certain forms of lymphoma and cancer of the lymph nodes, cancer of the uterus, and cancer of other and unspecified male genitalia occur equally or more frequently in nonurban areas than in central city areas. Thus mortality due to almost all forms of cancer is more frequent in the central portion of metropolitan areas of the United States.

Of other diseases, however, a fairly large proportion are equal in metropolitan and nonurban areas, or may be excessively high in the latter, examples being hypertension, rheumatic fever, asthma, influenza, acute poliomylitis, appendicitis, gastritis, duodenitis, colitis, enteritis, infectious and parasitic diseases other than tuberculosis, syphilis, accidents including motor vehicles, complications of pregnancy and of childbirth, and other diseases of early infancy and immaturity.

In sharp contrast to these findings are some diseases which might reasonably be suspected to be allied with air pollution, such as bronchitis, bronchiectasis, and emphysema. Other diseases which might not be influenced by air pollution, or for which no reasonable assumption can presently be made, include arteriosclerotic heart disease, chronic rheumatic heart disease, ulcer of the stomach and duodenum, diabetes mellitus, and cirrhosis of the liver.

These preliminary data, then, indicate that certain conditions, especially certain types of cancer, appear to be more frequently associated with urban living than might be expected by chance. There are some diseases which have higher death rates which might be explained on the basis of poor medical care in nonurban areas, or in some cases on the suspicion that people tend to go to metropolitan areas for medical treatment of serious conditions, so that the metropolitan death report data is artificially high. It would not appear, however, that this would tend to cause a gentle gradation of ratios as seen in the data for cancer of the trachea, bronchus, and lung or of emphysema.

The next step, then, is to attempt to investigate certain factors associated with urbanization and metropolitan areas which might show a correlation with the incidence of death.

Air Pollution Indices and Mortality Data

Fifty causes of death were chosen from the original 102 to develop correlation coefficients with the air pollution indices. This first choice was dictated by practical necessity; future plans will entail the selection of data for the remaining statistics.

The 50 causes were analyzed with some 30 different indices which included city-size, industrialization, age, sex, population density, and others thought to be related to air pollution. None had significantly high correlation coefficients; several had coefficients between 0.30 and 0.50, which were high in relation to the others. Since, by chance, a few high coefficients would be expected, only those causes of death which had a large number of coefficients in this range, from the large number of correlations done, were selected for study. Five causes of death in white males were found to have the largest number of high correlation coefficients with these indices: cancer (malignant neoplasm) of the trachea, bronchus, and lung; cancer of the stomach and esophagus; arteriosclerotic heart disease, including coronary disease; chronic endocarditis (not specified as rheumatic) and other myocardial degeneration; and mortality from motor vehicle accidents.

In the discussions to follow, deaths from motor vehicle accidents are omitted, since this correlation was a highly negative one. (That is, as city-size, industry, gasoline-sales and similar indices increase, accidental motor vehicle deaths decreased.) The assumption is made that increasing traffic complexity, and resultant decreasing speeds, reduces vehicular deaths in large cities, although not necessarily decreasing the number of accidents. Certainly, if air pollution increases as expected under these conditions, then it is not a directly causal factor in most of these deaths.

The other disease conditions mentioned above showed high positive correlations with most of the indices, especially those which might relate to increasing air pollution. In attempting to understand better and to develop means of interpreting these findings, the data were then examined by geographic distribution, city-size, industrialization, and other indices as described below.

Total gasoline service station sales has been selected as an index of total

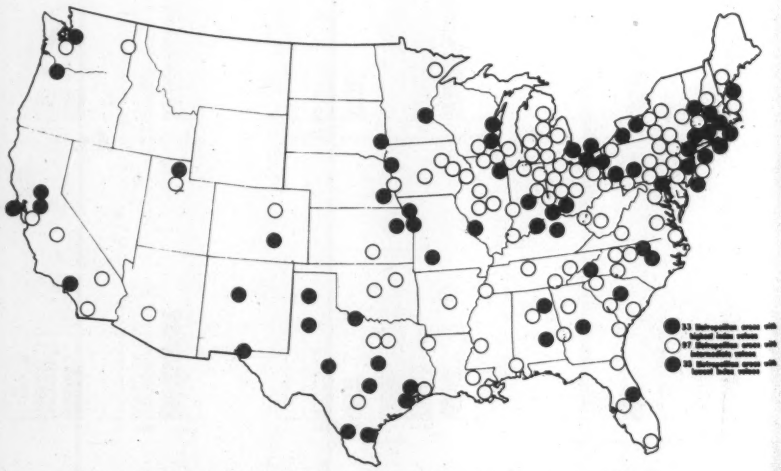

Fig. 6. Comparative index values in 163 metropolitan areas. Index 1.

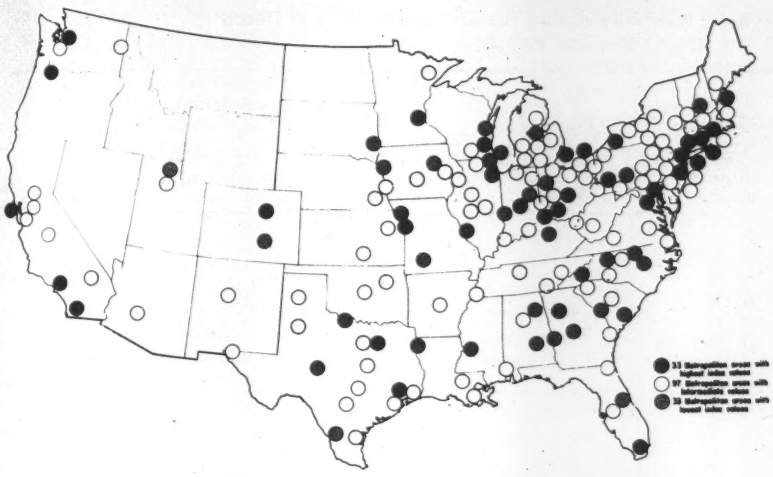

Fig. 7. Comparative index values in 163 metropolitan areas. Service station sales.

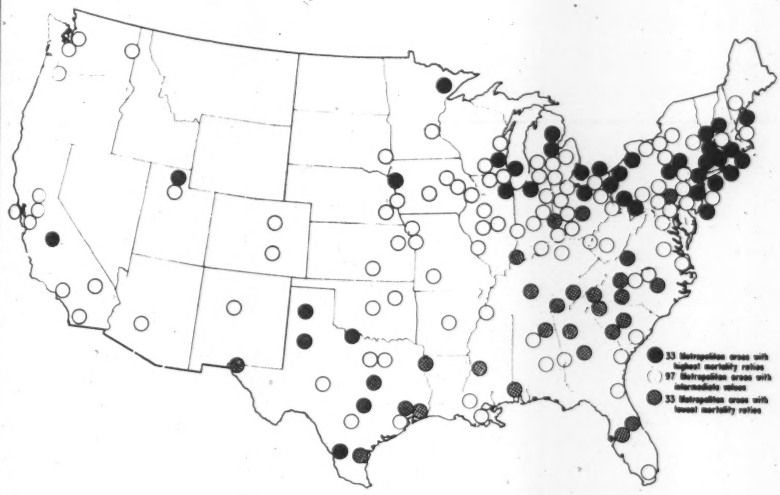

Fig. 8. Comparative mortality in 163 metropolitan areas. Malignant neoplasm of esophagus and stomach (150, 151). White male population.

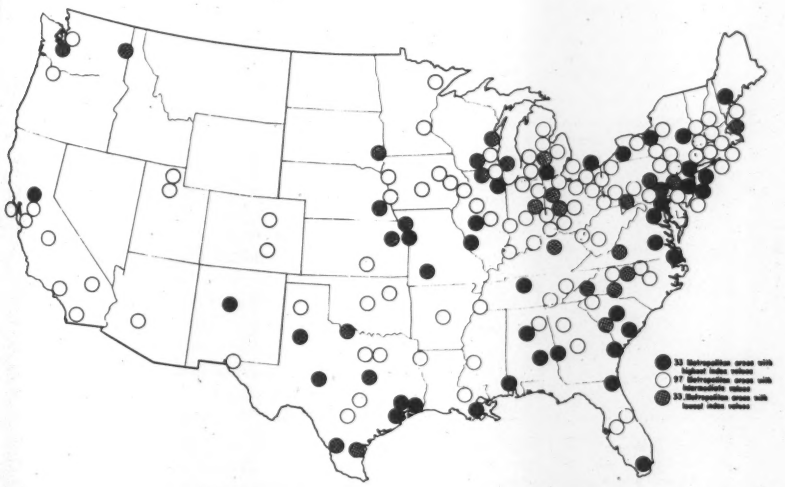

Fig. 9. Comparative mortality in 163 metropolitan areas. Malignant neoplasm of trachea, bronchus, and lung. (162, 163) White male population.

potential exposure to vehicular traffic pollution. A per capita consumption figure does not give evidence of the total "load" within the metropolitan area. That other total consumption data, both realistic and absurd, would show similar types of increase by city-size, is assumed.

On Fig. 6 are shown the cities with the highest values for Index I, which is the industrialization index that Mr. Manos has described. Fig. 7 shows the cities with the highest index values of service station sales, which represent presumably an estimate of gasoline consumption by automotive vehicles. The data show the 33 cities on each map which have the highest values. Twenty-six of these cities are represented on both maps. Both these indices correlate with city-size; in general the larger cities will have a higher index for industrialization and a higher value for gasoline sales. There are, however, some important exceptions.

Fourteen of these 26 cities, represented in both index maps, are included in the top 33 cities, rated by the mortality ratios for stomach and esophageal cancer (Fig. 8). Thus cancer of the stomach and esophagus is suspected to be in some way associated with city size, urbanization and the attendant increased industrialization and gasoline consumption of metropolitan areas, which factors may relate to air pollution.

Fig. 9 shows the distribution of the 33 cities with the highest death ratios of cancer of the trachea, bronchus, and lung in white males. The distribution is dissimilar from that shown for cancer of the esophagus and stomach, and shows several cities in the southeast and middle atlantic areas, particularly along the coast, which do not correspond with either the index values for industrialization or gasoline usage.

The following cities were included in both maps as having high death ratios for both lung cancer and stomach cancer: New York, Chicago, Philadelphia, Newark-Jersey City, Cleveland, and Buffalo. These cities are in order, the first, second, fourth, fifth, eleventh, and fifteenth largest cities in the country. The third largest city, Los Angeles, has neither an excessively high lung cancer nor stomach cancer ratio. Detroit, the sixth largest city, is high for stomach cancer but not cancer of the lung. (See also Tables I and II.)

As shown in Fig. 10 and 11, lung cancer in males increases directly as city size and total gasoline consumption increase. That this association with city size is not related entirely to differing smoking habits is suggested in Fig. 12.

An interesting association is developed in the distribution of arteriosclerotic heart disease in white males, which is similar to that of cancer of the trachea,

Table I—Median Values of Mortality Ratios for Selected Causes of Death by Size of Metropolitan Area

Size of Area	Number of Cities	Malignant Neoplasm of Trachea, Bronchus and Lung 162–163	Malignant Neoplasm of Esophagus and Stomach, 150–151	Arteriosclerotic Heart Disease Including Coronary Disease 420	Chronic Endocarditis Not Specified as Rheumatic and Other Myocardial Degeneration, 421–422	Ulcer of Stomach and Duodenum 540–541
			White Male			
50,000– 99,000	15	1.10	1.04	1.19	0.89	1.16
100,000–199,000	56	1.34	0.94	1.30	0.88	1.30
200,000–299,000	31	1.30	1.03	1.26	1.06	1.63
300,000–399,000	14	1.56	1.11	1.24	1.00	1.52
400,000–499,000	9	1.60	1.07	1.35	0.86	1.44
500,000–599,000	13	1.61	1.15	1.29	0.92	1.72
600,000–999,000	10	1.64	1.09	1.38	0.72	1.60
1,000,000+	15	1.89	1.41	1.38	1.10	1.70
	163					
			White Female			
50,000– 99,000	15	0.18	0.49	0.50	0.58	0.28
100,000–199,000	56	0.28	0.48	0.54	0.63	0.28
200,000–299,000	31	0.29	0.54	0.57	0.77	0.32
300,000–399,000	14	0.30	0.52	0.54	0.70	0.32
400,000–499,000	9	0.30	0.53	0.63	0.80	0.24
500,000–599,000	13	0.30	0.58	0.58	0.66	0.36
600,000–999,000	10	0.33	0.53	0.59	0.68	0.36
1,000,000+	15	0.34	0.66	0.67	0.82	0.35
	163					

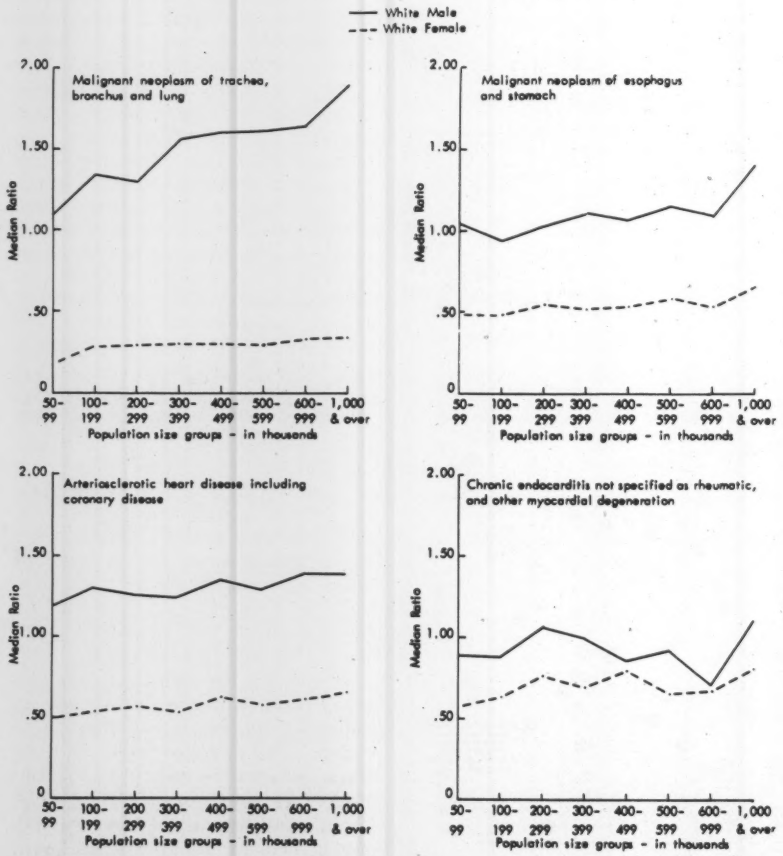

Fig. 10. Trends in mortality ratios for selected causes of death in metropolitan areas grouped by population size.

bronchus, and lung. Twelve cities are represented in both groups. Chronic endocarditis (and other myocardial degeneration), groups itself in a geographic distribution similar to that of cancer of the stomach and esophagus. Thirteen cities are represented in both groups. (Fig. 13 and 14).

Another group of indices was developed in an attempt to clarify sources of air pollution. Thus, in Fig. 15, the four diseases previously described, malignant neoplasm of the esophagus and stomach; neoplasm of the trachea, bronchus, and lung; arteriosclerotic heart disease, including coronary disease; and chronic endocarditis (not specified as rheumatic), and other myocardial degeneration, among white males, are shown together with several forms of fuel consumption measurements. The first bar represents the average of the ranks of the consumption of bituminous coal, anthracite coal, fuel oil, and all illuminating gas. The second bar represents the same figures weighted for coal and slightly weighted for fuel oil. The third bar represents all gas consumption in units of average million cu ft. Home heating is represented by the number of heating units times the number of degree days. Service station sales include all purchases made from service stations.

The value of the correlation coefficients is in general consistently higher for stomach cancer than lung cancer, and higher for these two causes than for the other two diseases. Stressing

coal consumption increases the correlation for stomach cancer and arteriosclerotic heart disease, and reduces it in lung cancer and chronic endocarditis. The two highest correlations with endocarditis are industrial gas consumption and home heating. Home heating also correlates well with stomach cancer. Service station sales correlate better with lung cancer than with the other three conditions.

Fig. 16 develops further the study of industrialization as related to the four causes of death. The first bar shows the correlation value for specific industries, ranked according to their potential for producing air pollution. The second bar represents industry in a nonspecific way; by percent of population engaged in manufacturing. Air pollution from the specific industries may be suspected to be of greater hazard in the production of these diseases; air pollution from total industries, not ranked as to their potential for contamination, should be less well correlated with these deaths. This appears to be true to some extent in the case of cancer of the stomach and esophagus, and to a very marked extent with cancer of the lung, trachea, and bronchus. Population density, the third bar, appears important in both conditions; less significance appears in all situations in connection with the two cardiac conditions.

Table II—Median Values of Mortality Ratios for Two Causes of Death by Population Density

Population Density per Square Mile for Metropolitan Area	Number of Cities	Malignant Neoplasm of Trachea, Bronchus and Lung, 162–163	Malignant Neoplasm of Esophagus and Stomach, 150–151
1–14	22	1.17	1.07
15–19	29	1.40	0.90
20–29	37	1.35	0.97
30–39	21	1.45	1.07
40–49	14	1.46	1.06
50–99	26	1.68	1.09
100+	14	1.85	1.42
	163		

Discussion and Conclusions

From the data presented there is no evidence to support an assumption of a causal relation between the diseases studied and air pollution. Many other factors exist, accounted for only partially or not at all, which may affect the distribution of deaths as shown. Socioeconomic status, genetic make-up, ethnic differences, and meteorological phenonema are examples of such factors.

One striking thing is the sex difference in the distribution of these diseases,

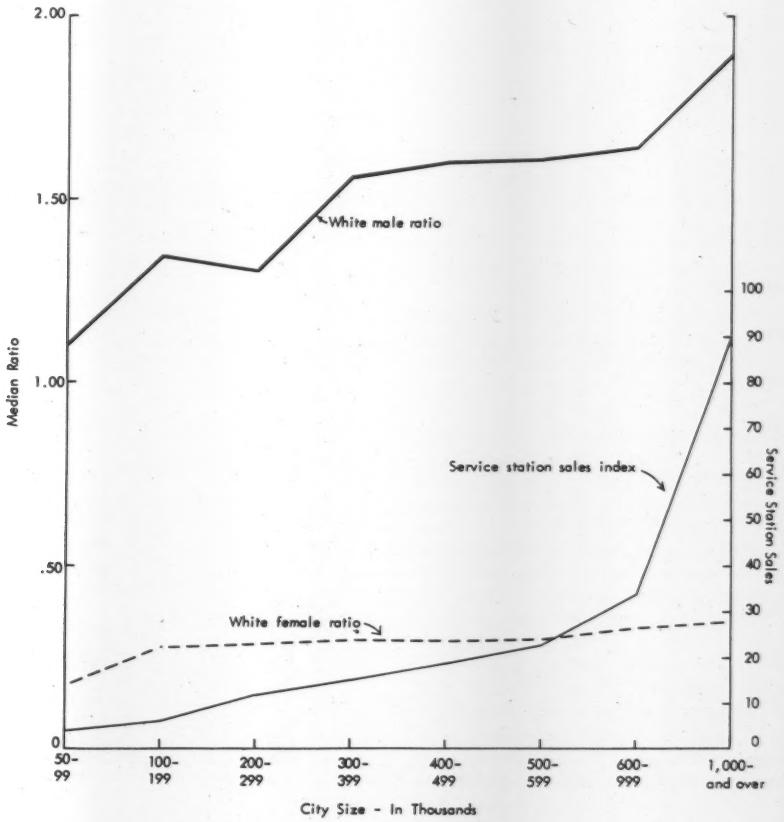

Fig. 11. Trends in mortality ratios for malignant neoplasm of trachea, bronchus, and lung as related to service station sales index in metropolitan areas grouped by population, size.

particularly lung cancer, as noted in Fig. 10. In the present state of knowledge only speculation is possible. Cancers in general cause a higher death rate in males, as do most of the other diseases throughout the life-span of the human being[8] as illustrated in part by the longer life-span of the female. This difference is often attributed to occupational exposures, habits, and other socio-economic differences. This relationship needs further intensive study, however, particularly in relation to hormonal factors and genetic structure.

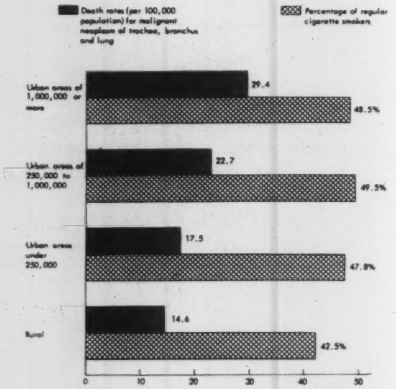

Fig. 12. Death rates for malignant neoplasm of trachea, bronchus, and lung among white males, and percentage of regular cigarette smokers among males* by type of area.

The possible relationship involving the other two diseases discussed: arteriosclerotic heart disease and myocardial degeneration, might be a secondary one. That is, the patient with an impaired circulatory system, especially the pulmonary circulation, may be rendered more susceptible to acute and chronic episodes of air pollution. There is some evidence to support this in studies by others in England.[9,10]

There are sufficient statistical relationships in this work, however, to indicate the need for further research and study. At this stage emphasis should not alone be on the diseases mentioned but on others as well, both to serve as a control for study and as indicators of other environmental and biological factors. Further pursuit, involving the data at hand, must be attempted in order to proceed by successive approximation to a more clear-cut association. The mechanism of experimental epidemiology, toxicology, and physiology, with study of whole community populations for their patterns of mortality and morbidity, will have to be undertaken before we achieve clarification of the relationship between air pollution and disease, if any exists.

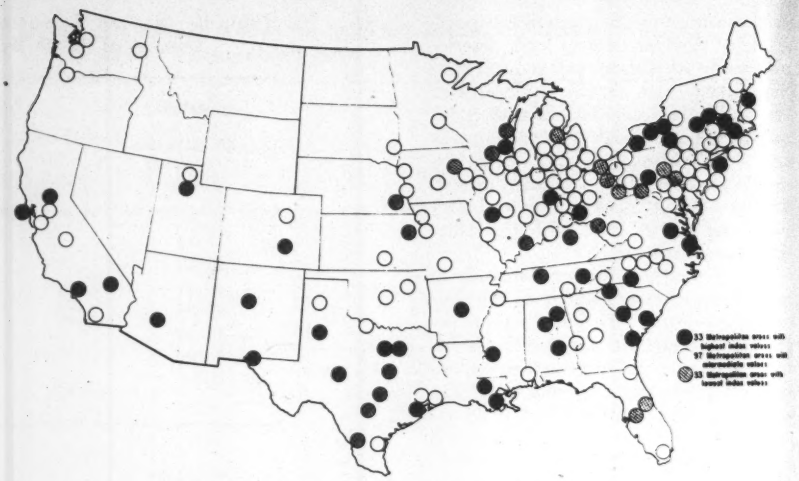

Fig. 13. Comparative mortality in 163 metropolitan areas. Arteriosclerotic heart disease, including coronary disease (420). White male population.

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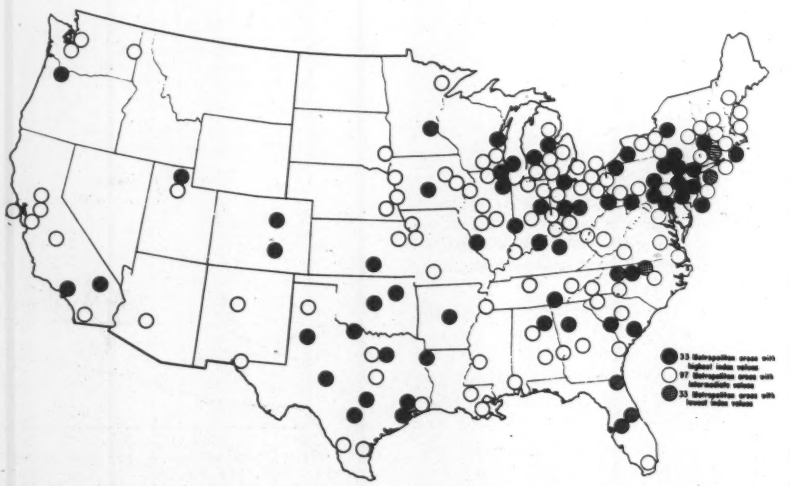

Fig. 14. Comparative mortality in 163 metropolitan areas. Chronic endocarditis not specified as rheumatic, and other myocardial degeneration (421, 422). White male population.

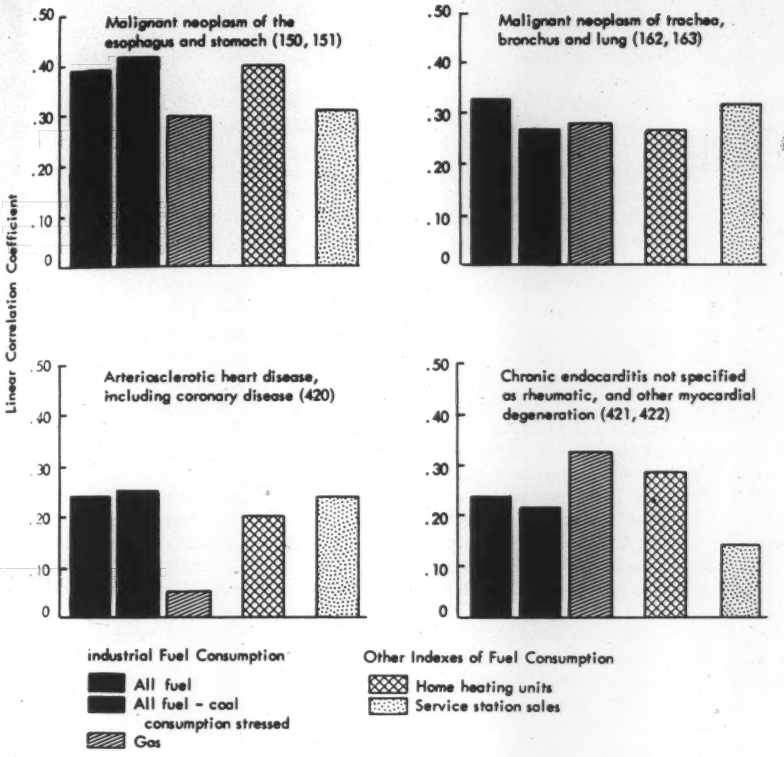

Fig. 15. Correlation between mortality among white males and fuel consumption indexes.

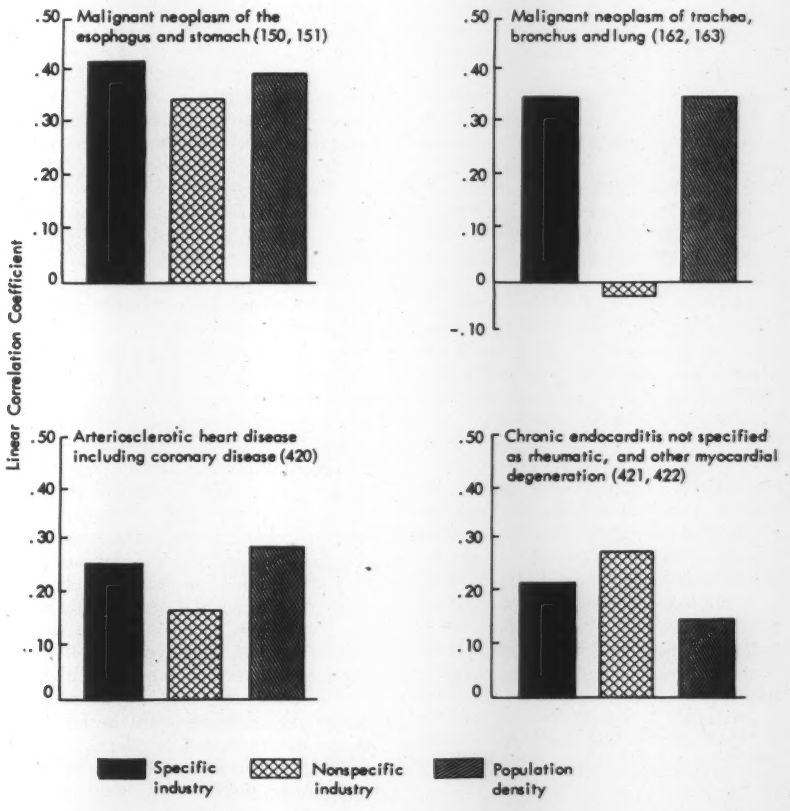

Fig. 16. Correlation between mortality ratios and major index types.

Air POLLUTION *and* HEALTH*

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So much has been written and said about air pollution that it is quite difficult to sort out fact from fancy, and discuss it either specifically or intelligently. The fact is that air pollution is becoming increasingly serious as population growth and industrial expansion add to the volume of pollutants discharged into the far-from-limitless ocean of air that surrounds us.

The problem of air pollution has received considerable attention from governmental bodies, industry, and voluntary individual organizations. Atmospheric pollution is not new or even recent. As a result of either natural phenomena or because of mankind's activities, some degree of atmospheric contamination has been present since the earth's formation. It is probably true that there is no such thing as absolutely pure air. We all are aware that the degree of contamination of the air and with what it is contaminated, varies greatly from place to place. The degree of air pollution depends upon the source of the contamination. Public attention has been forcefully drawn to the problem of air contamination by disastrous episodes that have occurred—for example, the heavy smog in October, 1948 that settled over the town of Donora, Pa.; or the November, 1950 incident at Poza Rica, Mex., where many people were either killed or affected by exposure to hydrogen sulfide emitted from an adjacent oil refinery. These episodes were acute and resulted from a combination of several factors, not the least of which was the weather.

A physician being called upon to attend individuals who have been exposed to some toxic vapor, gas, or dust is hard pressed, first of all, to know the causative agent, and secondly, when he finds out the cause, the treatment of it. For example, deaths have occurred as a result of beryllium exposure; livestock damage can be caused by eating forage contaminated with lead and fluoride compounds; vegetation can be damaged by sulphur dioxide. Just how does one treat these conditions other than remove from exposure and treat symptomatically? What are the antidotes?

Pollution of the air by allergens such as pollens is a well-recognized phenomena. The type of allergen varies from place to place. Treatment is desensitization or removal from exposure. Unfortunately, many persons have multiple sensitivities which makes both diagnosis and treatment difficult.

Studies by the Los Angeles Air Pollution Commission have established that oxygen and ozone convert hydrocarbons in the atmosphere into aldehydes, glycols, epoxies, acids, peracids, etc. Such materials largely account for the chemical composition of the Los Angeles smog. Many polynuclear hydrocarbons, tar particles, and dust particles are also present.

In a recent edition of the *Los Angeles Times* there was an article discussing the pollution of the air by tire dust. Much has been written about the ever constant pollution of the air by the fumes from automobiles. It has been established that there is radioactivity produced in the atmosphere following nuclear explosions. Waste from nuclear plants may contaminate the atmosphere, nearby soil, and water. Again, what is the treatment for exposure to these materials? It appears to be primarily removal from contact and then symptomatic therapy.

Lay individuals and groups are prone to immediately declare that any visible particulate matter or obnoxious odor are detrimental to health without any regard being given to the type or source of the offending material. The physician is just as hard pressed to interpret air pollution data and endeavor to find from it a sound therapeutic approach to the handling of exposed victims. The fact that man-made smog can be constantly annoying and occasionally lethal in a few isolated cities, is no news to anyone. The fact that every large city in the world may have such conditions in the future creates a posing problem for the physician along with the air pollution control scientist or official.

Mills[1] concludes that there is no longer reasonable doubt that Los Angeles smogs are related to very considerable increases in respiratory and cardiac deaths. He presents evidence for ample justification for smog controls to prevent atmospheric ozone concentrations above 0.2 ppm, and perhaps even lower levels. The combined effect of the many air pollutants in urban air in various areas has not been studied. It is recognized by medical research workers that there is an unknown connection between certain types of air pollution, particularly those types that irritate air passages and cause cellular toxicity or damage, and the generation of cancer.

Dr. Kotin[2] and associates state that, "A polluted atmosphere characterized primarily by oxidation products of aliphatic hydrocarbons may be a factor in human pulmonary carcinogenesis."

Pottenger[3] found that most physicians in the Los Angeles County area were agreed that cancer can result from air pollution. The unknown accumulative effects of smog on man may be partly surmised when one realizes that the growth rates of seedlings in the Los Angeles area were reduced $^1/_2$ before anyone took notice of smogs there. It was later found that the air pollution was responsible for this reduced rate of growth.

As Went[4] so aptly observes, one of the greatest difficulties in dealing with smog is its many aspects. He calls attention to the fact that nature, as well as man, pollutes the air in "myriad ways," and air pollution is world wide.

One index for the measurement of health effects resulting from air pollution in a community, is the number of deaths. Mortality due to almost all forms of cancer is more frequent in the heavily populated metropolitan areas of the United States. A fairly large proportion of other diseases are more frequent in incidence in metropolitan than in nonurban areas. Certain conditions, especially certain types of cancer, appear to be associated more with urban living than might be expected by chance. Two factors may influence this—poor medical care in rural areas and the tendency of persons to go to urban centers for treatment of serious conditions. However, present data does not support

* Presented Annual Meeting, East Central Section, Air Pollution Control Association, Akron, Ohio, September 11, 1958.

an assumption of a causal relation between any disease and air pollution. Many factors—socio-economic, genetics, ethnic, meteorologic, for example, — may affect the distribution of deaths. One striking fact is the sex difference in the distribution of lung cancer. Although this difference is often attributed to occupational exposures, habits, and other socio-economic differences, further study of hormonal factors and genetic structure is needed.

The causing of lung cancer by polluted air is believed to involve three factors: namely, carcinogens, irritants, and eluting (removal) factors. For example, carcinogens such as benzpyrene soon become adsorbed on soot particles in the atmosphere. They are not readily removed from these particles under normal conditions. The deposition pattern of particulate matter (soot) in the tracheobronchial tree is related both to particle size and to factors affecting the physiological activity of the bronchial epithelium. Ciliary activity and mucous secretion normally preclude the piling of particles on the epithelium. The respiration of such particles subsequent to or simultaneously with irritants such as occur in urban polluted atmosphere or in tobacco smoke, permit localization and accumulation. These irritating agents interfere with particle movement, and greatly reduce ciliary activity. Adsorbed carcinogenic materials disappear from soot following epithelial settling. These phenomena have been demonstrated in rats and doubtless occur in humans. Polar materials promote the elution of carcinogens from soot. The polarity of oxygen derivatives of gasoline is marked. Polar derivatives of pyridine occur in cigarette smoke. There is evidence that sex hormones influence elution, the tendency for elution being greater in males than in females.

The effect of tobacco smoke is a minor part of the pollution picture. It is an irritant and an elutant. Patients with cancer of the lung and larynx always include significantly larger percentages of smokers than nonsmokers. Cancer of the respiratory passages is also related to the amount of tobacco used. Cigar and pipe smoking appear to be more closely associated with cancer of the larynx than with lung cancer.

To allay their fears the public needs to be informed in nontechnical terms of the facts concerning air pollution. Both industry and medicine should work to spread accurate information among their employees and patients. For example, a fact that needs publicity is that a person is more apt to suffer from radiation poisoning because of too frequent or too prolonged exposure to x-rays than from the radioactive fallout from nuclear bomb explosions.

Information about the unknown can be discovered only by further experimentation and investigation. It is important to the human race for science to carefully study this fantastic problem of air contamination so that adequate safeguards against its hazards can be established. If we let mob hysteria develop through ignorance, we may prevent the progress which can be made in medical research for the saving and prolonging of life.

It can be concluded that the pollution of the atmosphere with materials of natural, artificial, or industrial origin is associated with a frequent, and apparently increasing, occurrence of acute and chronic disease. This is especially true of those diseases involving the respiratory tract and the skin. The assumption that all air pollution results in human disease cannot be supported until conclusive studies have been made as to just what is polluting the air. Then and only then can the health hazards be evaluated. It certainly stands to reason that all air pollution does not have an adverse effect on health. Everyone who smokes will not get a lung cancer. Everyone who lives in an industrial community will not die because of the air he breathes.

On the other hand, there is nothing so vital to life as pure air. Every effort should be made to secure what appears at present to be an unobtainable necessity. The physician can, in most instances, make the diagnosis of the presence of a pathological process in the body. In many cases he can, by treating, cure or alleviate the condition. He is hard pressed to relate the cause of the condition to some particular air contaminate.

We humans have the unfortunate ability of being able to contaminate any and everything with which we come in contact. Science must teach us how to decontaminate ourselves and our surroundings. If we do not, we will eventually find our world so polluted that we cannot live on it.

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Facilities and Techniques for MAINTAINING *a Controlled* FLUORIDE ENVIRONMENT *in Vegetation* STUDIES*

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Injury to various species of plants growing in the vicinity of certain industrial areas has been attributed to elevated levels of atmospheric fluorides. To critically evaluate the effects of any atmospheric pollutant on vegetation, it is necessary to compare plants grown in the presence of the pollutant with plants grown in its absence, with all other environmental conditions being the same.

Since an enclosure of some type is necessary in order to control the composition of the atmosphere, consideration must be given to the plant environment within the enclosure in relation to natural plant habitat, and also to keeping conditions the same in different enclosures being compared. Ordinarily plants grown in greenhouses or similar environmental chambers are exposed to abnormal conditions as compared to plants grown outside the enclosures. For example, the light intensity is frequently greatly reduced, and the humidity is usually much higher within the greenhouses or chambers. There are indications that the response of plants to atmospheric fluorides and to other atmospheric pollutants is affected by major differences in such factors as temperature, light, humidity, and soil moisture relationships. It is essential, therefore, that abnormal environmental conditions be avoided if meaningful, quantitative growth measurements are to be made on plants that are grown in enclosures for a long period of time.

Consideration must also be given to the atmospheric fluoride treatment used. This should also simulate realistic field conditions if effects on growth, yield, physiological processes, or even visible leaf symptoms are to be comparable to those that might be produced in the field. Most investigations with fluorides to date have been of a short duration, and the fluoride concentrations used have almost always been many times higher than concentrations occurring in the field around modern industries. In contrast to sulfur dioxide and certain other pollutants, practically all effects of fluorides on plants in the field are caused by slow accumulation over relatively long periods of time.

This paper describes facilities, equipment, and techniques that have been developed by the United States Steel Corporation to study the effects of fluorides on plants, with considerable care being exercised to maintain conditions in the environmental chambers comparable to those in the field outside. The facilities were designed primarily for studying the effects over a long period of time of the low gaseous fluoride concentrations that may be found in certain atmospheres, but they are equally adaptable to study of the higher concentrations required to affect most plants. Although these facilities are unique in many respects, they incorporate ideas developed by many other investigators for air pollution studies. Thomas, et al.,[13] described small air-conditioned greenhouses used over sand culture beds, and Thomas and Hill[14] also used portable celluloid-covered chambers for studying plants growing in the field. A variety of environmental chambers has been used by other investigators to study the effects of air pollutants on plants.[1,2,4,10,11,15]

Greenhouses

A set of 3 greenhouses used for atmospheric fluoride studies are shown in Fig. 1. These greenhouses are 36 ft long, 9 ft wide, and $8^1/_3$ ft high at the gable joint, giving a volume of 2025 cu ft. A different atmospheric fluoride treatment may be used in each greenhouse. Identical plantings are made in the same positions in each greenhouse to eliminate positional effects, i.e., the effects on plant growth of minor differences in light, air movement, and temperature in different parts of the greenhouse. With the exception of the fluoride treatments, all conditions in the three different greenhouses are kept the same.

The air circulating through the greenhouses is first drawn through lime-coated orlon bags to remove fluorides. Each greenhouse is equipped with a bag tower containing 96 bags 5 in. in diameter and 66 in. long. Gaseous fluorides react with the lime, and particulate fluorides are filtered out by the bags. The visible appearance of sensitive indicator plants and chemical analyses indicate that the removal of fluorides is essentially complete. This method of air purification is preferable to the water-scrubbing method usually used, because it does not change the humidity of the air. This is particularly important if unfiltered, ambient air is circulated through 1 greenhouse for comparison with filtered air in another.

Air is circulated through each greenhouse at two air changes per minute. Fluorides are rapidly removed from the air by vegetation and by adsorption on the various surfaces within a greenhouse, so rapid air circulation is essential for the maintenance of the atmospheric fluoride concentrations as well as for the control of temperature and humidity. The air enters each greenhouse at 7 sites equally spaced along the base of one side and is directed up and across the top of the greenhouse. The air is exhausted through 7 ducts located beside the inlet ducts. This tends to give the air a circular motion through the greenhouses: up and across the top, down the opposite side, and back across the bottom. Even with two air changes a minute passing through the greenhouses, the rate of air movement in the vicinity of the plant leaves averages less than it does under field conditions. This possibly results in a lower transpiration rate of the plants grown in the greenhouses than in field plantings.

Solar radiation tends to elevate the temperatures in greenhouses above the

* Presented at the 51st Annual Meeting of APCA, Sheration Hotel, Philadelphia, Pa., May 25–29, 1958.

Fig. 1. Greenhouses used for atmospheric fluoride studies.

outside temperature, even when a rapid rate of air exchange is used. The methods usually employed for cooling greenhouses are objectionable because they alter other conditions. Coating them with lime or shading them by other means alters the intensity and quality of the light, and the use of evaporation coolers increases the humidity of the air. The greenhouses described are cooled by circulating cold water through banks of finned coils in the air inlet ducts. With this system it is possible to keep the temperatures in the different greenhouses nearly the same, and within 2 or 3° of the outside temperature, during the warmest months of the year. The humidity is essentially the same as outside, being increased only slightly by plant transpiration, and the light intensity is reduced only by the amount caused by the glass and the greenhouse framework. The greenhouses are heated during the winter months by circulating hot water through the finned coils. During summer operation the air is exhausted outside, but during cold weather, it can be partially recirculated if desired to conserve heat.

The plants are grown in a uniformly-mixed soil in plots in the floors of the greenhouses to avoid restricting the root zone and to provide normal soil water and nutrient relationships. Each greenhouse has 6 plots 3 x 5 ft in size on each side of a central walkway. A redwood duct-base around each plot permits the mounting of a small chamber over the plot if it is desired to isolate it from the rest of the greenhouse. The desired soil moisture conditions are maintained by the use of tensiometers. Fertilizer applications are designed to produce typical or normal growth of the crops being grown.

A large majority of the plants grown in these facilities have developed normal growth patterns. Several varieties have been rather succulent in their development, however, perhaps because of the lower rate of air movement within the greenhouses or the absence of exposure to hot, dry winds. The response of these plants to fluorides has not always been typical of field response. The possibility of overcoming this problem by using fans to produce additional air circulation within the greenhouses is being investigated.

A degree of replication can be obtained by growing several plots of the same crop in each greenhouse. If a number of plants are grown in each plot and a good deal of care is exercised in selecting uniform plants, reasonably conclusive results can be obtained with limited replication. If the treatments have no effect there is little cause for questioning the results. If they have an apparent effect it is usually advisable to repeat the study to determine whether the difference is due to the treatment or to some other cause.

Portable Chambers

Portable chambers of two different sizes are used for placing over crops growing in the field and for isolating individual plots within the greenhouses. These chambers are made of transparent Vinylite sheeting, attached to aluminum frameworks with hardwood strips.

The smallest chambers fit over the greenhouse plots (Fig. 2). They have single-pitched tops, and their volume is 76 cu ft. The chambers sit on 4 x 6 in. redwood ducts with holes bored in them at regular intervals, which serve as the air outlets from the chambers. Air is circulated through the chambers with blowers, entering at the top of one end. Uniform distribution of the air within the chambers is accomplished by blowing the incoming air through holes evenly distributed in Vinylite ducts that extend across the tops of the chambers and by operating 2 50-cfm circulating fans inside each chamber.

The large portable chambers have double-pitched tops, and their volume is 153 cu ft. They are 5 ft wide and 6 ft long and sit directly on the ground. Air from a blower enters each chamber through an opening in one of the gables, is directed downward by a baffle, and is exhausted through a hole in the opposite gable. Circulating fans are used within the chambers. The height of these chambers has been extended an additional 4 ft for use over small trees by using a base made of polyethylene on a wooden frame (Fig. 3).

An advantage of using portable chambers over plots in the field is that the plants can be grown under field conditions and covered with the chambers only for whatever period of time the fluoride treatments are being applied. If there are sufficient fluorides in the ambient air to effect the plants being studied, this procedure does not give a control treatment that has not been subjected to fluorides. When a chamber is placed over a crop for a fluoride treatment, an identical chamber has to be maintained over another plot as control. The temperature and humidity can be kept very near those outside by using rapid air circulation through the chamber (two or three air changes a minute). Since there is usually greater density of vegetation in a chamber than in a greenhouse, less difficulty is encountered in avoiding elevated temperatures. Fairly good removal of fluorides from the incoming air has been effected by drawing the air through dacron blanket felt dusted with lime and attached to a wooden framework over the blower.

It is easier to get replications with chambers placed over crops in the field, and reliable yield data can be obtained with most crops. It is also possible to measure the rate of photosynthesis of plants growing in the

Fig. 2. Small plastic chambers over plots within greenhouse.

chambers and to use it as a direct measure of their rate of growth. The net rate at which carbon dioxide is being utilized by the plants is determined by measuring continuously the carbon dioxide content of air drawn from the inlet and outlet ducts of the chambers. Measurements of this type are of considerable value when direct yield data can not be obtained.

Air Flow Measurements

Some means of measuring the rate of air flow through the environmental chambers is necessary to facilitate the maintenance of comparable conditions within different chambers in a given study, to permit regulation of the fluoride treatments, and to permit the measurement of the rate of carbon dioxide utilization in photosynthetic studies. Several different methods of measuring air flow may be used.

The air flow into the greenhouses is measured satisfactorily with a Pitot tube. Jeweled precision anemometers (Short and Mason 3112 airmeters) are used for measuring the air flow through the portable chambers in certain studies where the highest degree of accuracy is not required. When an anemometer is used in a small duct it indicates an air flow rate somewhat greater than that which actually occurs because of the reduction in the cross section area of the duct by the body of the anemometer. For the greatest accuracy the anemometer should be calibrated against a precision orifice for the position and duct size for which it is to be used.

The accuracy of photosynthetic measurements is directly related to the accuracy of the measurement of air flow through the chambers. The use of orifices to measure air flow has been suggested by Setterstrom.[10] It has been found that precision orifices in the air inlet ducts provide a very effective way of controlling and measuring the air flow through the chambers when a high degree of accuracy is desired. Air from a pressure blower passes through an aluminum pipe with the orifice plate held in an adapter (Fig. 4). Taps at appropriate distances from each side of the orifice plate permit the measurement of the pressure drop across the

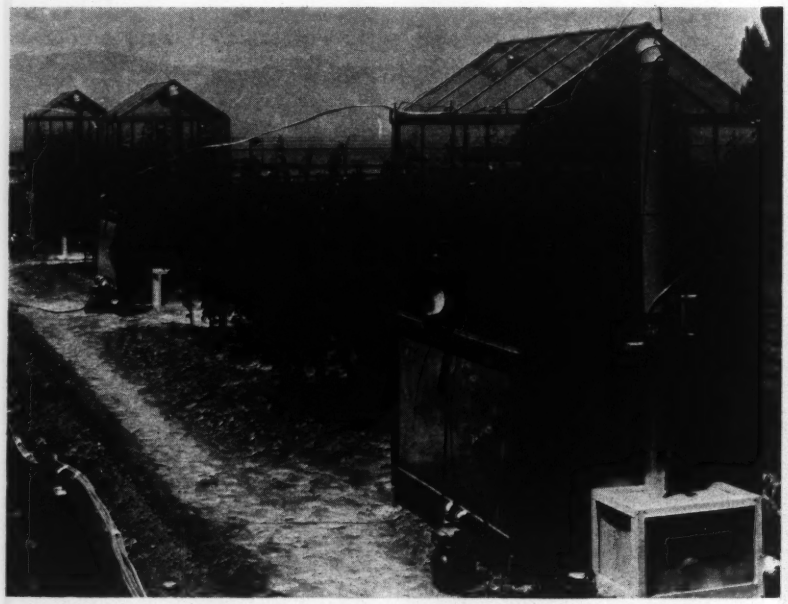

Fig. 3. Portable chambers over apricot trees in the field.

orifice. For greatest accuracy a pressure drop of several inches of water is necessary. By using an orifice of the proper size and adjusting the pressure drop by means of a movable plate over the inlet side of the blower, any air flow rate within a given range can be obtained. This method of measuring air flow is very simple and has proved superior in accuracy to either Pitot tubes or anemometers.

Method of Introducing Fluorides

One of the problems in studying the effects of atmospheric fluorides on plant growth is the control of the fluoride concentrations within the chambers. Several methods of introducing fluorides, particularly at high concentrations are described in the literature.[2,4–6] For one reason or another none of the methods described were considered completely satisfactory. Most of the equipment requires frequent attention. None of it has the compactness and ease of portability that is desirable for use on a variety of portable and permanent installations, while at the same time permitting the degree of control essential for critical experimentation.

A method of accurately injecting gaseous fluoride into the air stream entering a chamber or greenhouse was developed. The equipment is very simple and compact and permits an accurate control of emissions, even at very low fluoride concentrations over a long period of time.

Air is bubbled through an aqueous solution of volatile fluoride. When the temperature and concentration of the solution and the rate of air flow through the solution are kept constant, the rate of fluoride emission is constant. The air is bubbled through distilled water at the same temperature as the flouride solution to saturate it with water vapor prior to its passing through the solution. This prevents any appreciable change in the fluoride concentration over long periods of time.

The apparatus used in these studies is shown in Fig. 5. Air is pumped through a flow meter, F, that is calibrated in l/min, through a perforated nozzle immersed in distilled water, A, through another perforated nozzle immersed in the hydrogen fluoride solution, B, and out through the exhaust tube, C. The two polyethylene bottles, A and B, are immersed in a controlled temperature water bath in a polyethylene safety jar, D. For the portable chambers, bottles A and B are 32 and 16 oz, respectively, and a 1-gal safety jar is used. For the greenhouses a larger fumigator is used with 2 half-gallon bottles in a $3^1/_2$-gal safety jar. The nozzles are made by sealing the end of $^1/_4$-in. polyethylene tubing and drilling

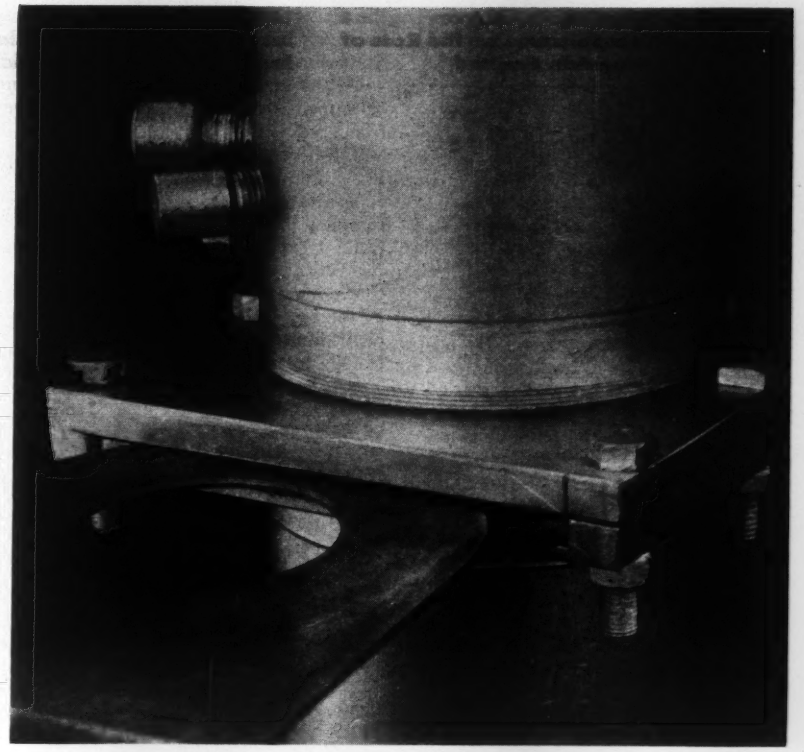

Fig. 4. Precision orifice used for air flow measurement.

holes in the sides near the end with a jeweler's drill. The polyethylene exhaust tube, C, is wrapped with asbestos covered chromel wire, coated with neoprene, and maintained at a temperature of 147°F to prevent condensation or adsorption of fluoride.

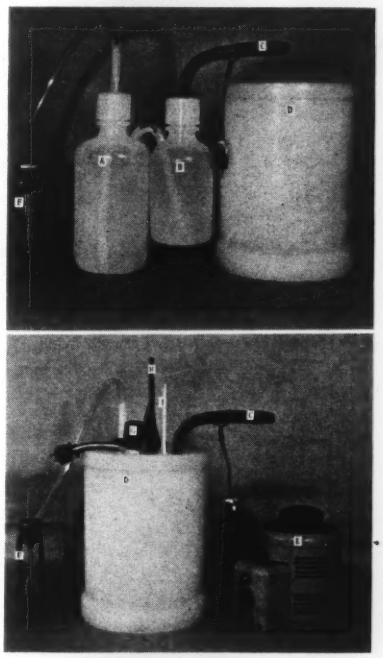

Fig. 5. Disassembled (above) and assembled (below) fumigation apparatus showing the following: distilled water bottle A, hydrogen fluoride solution bottle B, exhaust tube C, water bath D, transformer E, flow meter F, thermoregulator G, heater H, and thermometer I.

The rate of fluoride emission from the fumigator was measured by collecting the output in an impinger bubbler containing distilled water and determining the fluoride emitted per unit time by the method of Nielsen and Dangerfield.[9] A number of consecutive tests of the fumigator output when the conditions of operation were the same showed a standard error of only 0.76%. The procedure has proved effective for use with fluosilicic acid solutions as well as for hydrogen fluoride. When fluosilicic acid is used, a combination of hydrogen fluoride and silicon tetrafluoride gases is emitted. Approximately $^2/_3$ of the fluoride is in the silicon tetrafluoride form. In the presence of water vapor or high humidity, the fluorine may be in the fluosilicic acid form. Thomas[12] has found that relatively pure silicon tetrafluoride is obtained if the hydrogen fluoride from the fumigator is passed through a heated tube of silica gel.

The effect of varying the solution temperature is shown in Table I. These data show clearly the necessity of keeping the temperature constant if consistent results are to be expected. A temperature of 100°F was maintained in all subsequent work reported here.

In Fig. 6 rates of fluoride emission from fumigators containing several different concentrations of hydrogen

Table I—The Effect of Varying the Solution Temperature on the Rate of Fluoride Emitted

Temperature (°F.)	Rate mgs of F/hr*
80	3.7
90	5.1
100	7.8
118	14.3

* 1.1 *M* HF solution, rate of air flow 1.23 l/min.

fluoride and fluosilicic acid are plotted for various rates of air flow. By adjusting the solution concentration and air flow rate, fluoride emission can be varied over a wide range.

Air flow through the environmental chamber is regulated by means of a movable plate over the blower inlet and measured by one of the methods described in the previous section. The gaseous fluoride is introduced into the air stream by placing the exhaust tube of the fumigator through a hole in the air inlet duct. The rate at which fluoride must be introduced to give a certain fluoride concentration in the incoming air is calculated for the selected rate of air flow, using data such as those plotted in Fig. 6.

The air in the chambers is sampled continuously throughout each study and analyzed for fluoride to show exactly what concentrations are present. The sampling is done with a Greenburg-Smith impinger absorber, and the analyses are made by the method of Megregian[7] as modified and adapted to use with an ion exchange resin separation technique by Nielsen.[8] The time periods covered by individual samples are chosen to fulfill the objectives of the particular study. To show the general trends of the fluoride concentrations, 24-hr samples are used. Samples covering shorter time periods are collected to detect variations within a 24-hr period. It is convenient to change 24-hr samples manually, but for shorter time periods an automatic sampler such as the one described by Hill, et al.,[3] is used.

When sampling air from an environmental chamber, thought should be given to selection of the place from which the sample is drawn. Even with good air circulation there are differences in the fluoride content of air in different parts of a chamber, particularly when there is abundant vegetation present. Since it is usually desirable to be able to interpret the results in terms of field conditions, the sampling site should be so located that the results can be compared to those obtained in field sampling.

The concentration of fluoride in the air within a fumigated chamber is usually found to be less than that of the incoming air because of absorption by the plants and adsorption by the chamber walls and soil. A similar difference has been found under field conditions when the fluoride content of air within or immediately above a crop has been compared with the fluoride content of air further above or away from the crop. For example, the atmospheric fluoride concentration at a permanent air sampling station located about 200 ft from a young orchard was compared for 15 days with the concentration in the vicinity of the trees. In comparison to the regular station the fluoride concentrations 5 ft above the trees, at the canopy level (8 ft from the ground and 1 ft from a tree), and below the trees (2 ft above the ground) averaged 10, 29, and 25% less, respectively. The extent of the difference in fluoride content between the incoming air and the air in a chamber is dependent on many factors, such as the rate of air exchange and the amount of vegetation. There are also unavoidable fluctuations in the fluoride content of the air within a chamber. The opening and closing of the plant stomata affect the rate at which the plants absorb fluorides. Adsorption is most rapid when the surfaces within the chamber are cool, and there may be some desorption from some surfaces when they warm up. Fluctuations in the atmospheric fluoride concentration within a chamber are much less than those encountered in the field because of the variations in meteorological conditions. At times it is desirable to more nearly duplicate field conditions in an environmental chamber by deliberately varying the fluoride emission from the fumigator to simulate field fluctuations from the mean. Extreme fluctuations should be avoided, however, or an atypical response may be obtained. With experience the extent of the reduction in the fluoride concentration within a chamber can be estimated, and the fumigator can easily be adjusted to approach very nearly any desired concentration.

Although it has not been thoroughly tested for anything but hydrogen fluoride and fluosilicic acid, limited data indicate that the fumigation equipment is equally useful for dispensing other volatile substances. In limited tests it has been used for dispensing ammonia from a solution of ammonium hyroxide, and nitrogen dioxide has been generated by bubbling the air first through formaldehyde and then through nitric acid.

Discussion

In addition to making possible a comparison of plants grown under different, controlled, atmospheric hydrogen fluoride concentrations, the greenhouses are designed to permit the study of the local or ambient atmosphere. By circulating ambient air through one of the greenhouses, filtered air through another, and filtered air with hydrogen fluoride added through the third, a direct measure can be made of any effects of the local atmospheric fluorides on plant growth. This is frequently the most direct approach to the study of a local problem.

A comparison of the effects on sensitive indicator plants of the ambient air and of filtered air containing the same concentration of fluoride as

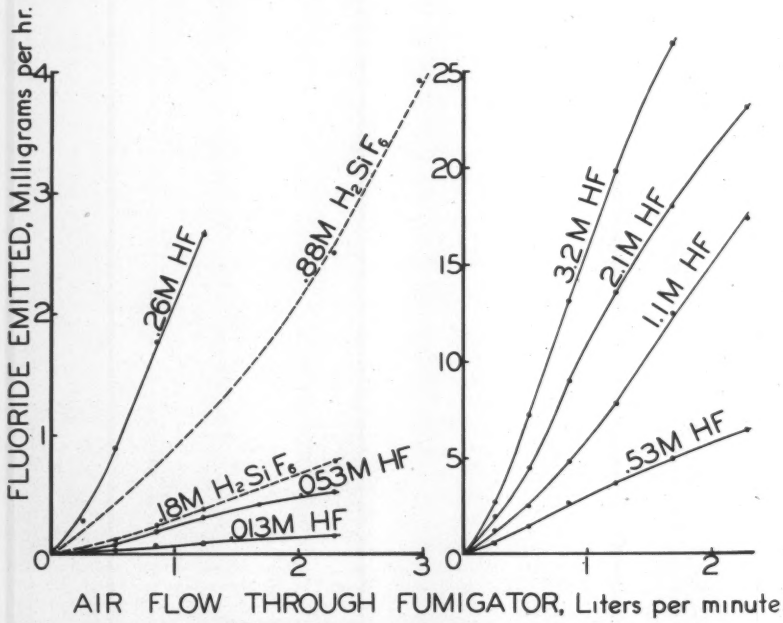

Fig. 6. Rate of fluoride emission from fumigator under various rates of air flow with several different solution concentrations of hydrogen fluoride and fluosilicic acid.

hydrogen fluoride gives a measure of the relative phytotoxicity of the local atmospheric fluorides in comparison to hydrogen fluoride. Since most research has been limited to a study of the effects of hydrogen fluoride or silicon tetrafluoride on vegetation, some knowledge of their relative toxicity to the ambient fluorides is essential. Frequently atmospheric fluorides are much less toxic than the hydrogen fluoride or silicon tetrafluoride forms.

A high percentage of the atmospheric fluorides in certain areas is in particulate form. The chambers described here have been used to compare the effects of a particulate fluoride (mostly calcium fluoride) and hydrogen fluoride. The particulate fluoride was found to have very little effect on plants, even at extreme concentrations.

These facilities have been used to study the effects of atmospheric fluorides on a number of different plant species. Concentrations of hydrogen fluoride ranging from 0.1 to 50 $\mu g\ m^3$ have been maintained continuously for periods ranging from several weeks to several months. The lower concentrations (from 0.1 to 0.5 $\mu g\ m^3$) might represent levels that actually occur in the field in certain areas, whereas higher concentrations were required to produce effects on most plants. Very complete measurements have been made to evaluate the effects of the treatments on the plants. Photosynthesis measurements have been made as was mentioned. Periodic observations of the appearance of the plants and measurements of shoot elongation, stalk or trunk diameter, leaf size and development, and final weight of various plant fractions have also been made. Periodic measurements have been made of the chlorophyll content and respiration rate of the leaves of several plant species. When visible symptoms of injury developed they were measured regularly and related to the atmospheric fluoride concentrations. The plant tissue was analyzed to determine the amount of fluoride accumulated under different treatments, and when the plants were grown to a regular harvest, the quality and keeping properties of the produce were evaluated.

Although the facilities, equipment, and techniques that have been described were developed primarily for study of the effects of fluorides on plants and have been used mostly for that purpose, they are equally suitable for studying the effects of many other atmospheric pollutants. With very little modification they could be used to study such materials as sulfur dioxide, ammonia, nitrogen oxides, and smog components. The ideas presented regarding the need for approximating field conditions in the environmental chambers will also apply to studies of other pollutants if the experimental results are to be applied to field conditions.

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EFFECTIVENESS of ODOR COUNTERACTANTS for the Treatment of Stack Gases*

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When unpleasant odors associated with gaseous discharges from industrial processes disturb a community, the peaceful existence of the manufacturing plant is seriously jeopardized and abatement measures are required. One abatement method which has been vigorously promoted during the past few years is the addition of other odorous substances to the effluent gas stream to counteract, mask or reodorize the objectionable gases emitted by the plant.

Although the use of odor counteractants (or odor masks) has been highly recommended, alleged successes are unsupported by the type of objective, factual data we consider necessary for other methods of air pollution control. Admittedly there are still serious gaps in our knowledge of physiological and psychological response to odor and there are formidable obstacles to be overcome in finding a suitable substitute for the human nose to evaluate odors, but we must also note that these difficulties have not been a restraining factor on the commercial exploitation of odor counteractants and odor masking agents.

Recently an opportunity occurred to make a series of tests on the effectiveness of odor counteractants for stack gas effluents and this study will be reviewed in some detail. The plant in question discharged 95,000–145,000 cfm of stack gas containing 100–200 ppm of H_2S and SO_2 plus traces of mercaptans not otherwise identified. The odor threshold for SO_2 is approximately 4 ppm; for H_2S, 0.2 ppm and for ethyl and methyl mercaptans, 0.0003 ppm. From these figures it is evident that very great dilution of the stack gases was required to reduce the odor below the sensory level.

In addition, the possibility that the several odors acting together intensified the effect could not be ruled out. In any case, the gases had an extremely unpleasant odor and the plant was engaged in serious litigation with surrounding residents because of alleged damage to health and property. During an extensive field sampling program over a period of many months it was never possible to detect more than a few tenths of 1% of sulfur-containing gases in the residential areas, which were located some distance from the plant, although under certain atmospheric conditions the characteristic stack gas odor could be detected up to one mile downwind. The introduction of odor counteractants into the stack (at a location approximately 15 ft below the outlet) had been underway on an experimental basis for several weeks. The opinions of the plant superintendent and other personnel regarding the effectiveness of the odor counteractant treatment were varied and there was no reasonable basis for making a recommendation to management on their continued use. Since routine application would require an annual expenditure of $5000–$10,000 for odor counteractant chemicals, additional information relative to the effectiveness of this treatment was considered essential.

It was noted that when the sky was overcast and the wind turbulent, the stack gases would strike ground level near the top of a ridge located about 1/3 of a mile away from the plant and at approximately the same elevation as the top of the stacks. The progress of the plume could be followed because condensation of the warm, moist gases made it easily visible. An odor panel of 10 individuals, including laboratory, clerical, and supervisory employees of the plant, was stationed on this ridge downwind of the plant on a day when the plume swept the top of the ridge at irregular, but reasonably frequent intervals. Arrangements were made to station a person (not one of the odor panel) at the plant to regulate the input of odor counteractant to the stacks in a random and unpredictable manner. Each member of the odor panel (at the test station located 1/3 mile from the plant) was required to sniff the gases and to record his opinion relative to: (1) the pleasantness or unpleasantness of the odor and (2) the rate at which the odor counteractant was being added to the stack gases, i.e., at the recommended rate, one half this rate, double the recommended rate or completely off. After each member of the panel had recorded his opinion, the individual controlling the input of odor counteractant was signalled to make a change (or no change, if he so decided). No individual on the odor panel had any knowledge of the order in which odor counteractants were added to the stacks until after the conclusion of the experiments. Efforts were made to eliminate smoking and comparison of answer sheets during the conduct of the experiment which took approximately 2 1/2 hr.

Table I shows the odor acceptability ratings of each of the 10 members of the odor panel for 8 odor tests. Due to a misunderstanding, some of the subjects reported their odor preferences in terms of "pleasant" and "unpleasant," others used the terms "objectionable" and "not objectionable," and some used both sets of terms interchangeably. Although it might be possible to make legitimate distinctions between the meaning of these various terms and to analyse the data on this basis, it is believed that the terms "unpleasant" and "objectionable" may be considered synonymous for the conditions of this experiment and that "pleasant" and "not objectionable" should be similarly regarded. This interpretation is entirely consistent with the instructions given to

* Presented at First Technical Meeting of the New England Section of APCA, Providence, R. I., May 8, 1957.

Table I—Odor Acceptability Ratings

Actual Rate of Application of Odor Counteractant	Observers' Estimate of Acceptability of Stack Gas Odor										No. Pleasant or Unobjectionable	No. Unpleasant or Objectionable
	A	B	C	D	E	F	G	H	I	J		
Recommended	Unpleasant	Unpleasant	Unpleasant	Unobjectionable	Unobjectionable	Unpleasant	Unpleasant	Unobjectionable	Unobjectionable	Unpleasant	4	6
None	Unpleasant	Objectionable	Unpleasant	Unpleasant	Objectionable	Unpleasant	Unpleasant	Unobjectionable	Unobjectionable	Unpleasant	2	8
Twice recommended rate	Unpleasant	Unpleasant	Unobjectionable	Unobjectionable	Unobjectionable	Unobjectionable	Unobjectionable	Unobjectionable	Unobjectionable	Objectionable	7	3
Half recommended rate	Unpleasant	Objectionable	Unobjectionable	Unpleasant	Unobjectionable	Unpleasant	Unobjectionable	Unobjectionable	Unobject tionable	Objectionable	5	5
None	Unpleasant	Unpleasant	Unpleasant	Unpleasant	Unobjectionable	Unpleasant	Objectionable	Unobjectionable	Unobjectionable	Unpleasant	3	7
None	Unpleasant	Objectionable	Unpleasant	Unobjectionable	Unobjection able	Unpleasant	Objectionable	Objectionable	Objectionable	Unpleasant	2	8
Recommended rate	Unpleasant	Objectionable	Unobjectionable	Unobjectionable	Unobjectionable	Unpleasant	Unpleasant	Unobjectionable	Objectionable	Objectionable	4	6
Recommended rate	Unpleasant	Unpleasant	Unobjectionable	Unobjectionable	Objectionable	Unobjectionable	Unpleasant	Objectionable	Objectionable	Objectionable	3	7

the odor panel prior to the start of the experiments. The pleasantness or unpleasantness of the odor is considered to be a more reliable guide to acceptability by the public-at-large than information on relative odor intensity or any other single odor characteristic.

It may be noted from the table that three of the observers (A., B., and J.) objected to the odor under all conditions and that four others (D., E., F., and H.) split their answers on the basis of 6 and 2. When the manner in which the odor counteractant was introduced into the stack is considered, it may be seen that in 3 of the 8 tests the recommended quantity of counteractant was used and in 2 others some amount of odor counteractant, although not the recommended amount, was added. Therefore, if the quantity of counteractant is critical, as is often claimed, a reaction ratio of 3 "pleasants" to 5 "unpleasants" should occur. Alternatively, if the quantity of odor counteractant is not critical, then there should be 5 "pleasants" (or "not objectionables") (corresponding to the 5 tests when some quantity of odor counteractant was used) to 3 "unpleasants" (or "objectionables") for the 3 tests when the odor counteractant was completely off. Instead, for the 3 tests in which recommended quantities of odor counteractant were used we find that only 11 of the 30 possible opinions were favorable and 19 unfavorable. When the odor counteractant was turned off, the number of unfavorable reactions was 23 out of a possible 30. Thus there is a measurable difference in favor of the use of odor counteractants (i.e., the number of unfavorable responses dropped from 23 out of 30 to 19 out of 30 when normal quantities of odor counteractant were used) but it is doubtful that this difference is of a very high order of significance. It is especially pertinent to note that even when the recommended quantity of odor counteractant was used, the reaction of the odor panel was almost 2 to 1 that the odor was "unpleasant" or "objectionable." This result is all the more remarkable because 9 out of the 10 members of the odor panel had worked at this or similar plants for 1 to 15 yr and they were all thoroughly familiar with, and accustomed to, the characteristic plant odor. The 10th member of the odor panel was not an employee but was accustomed to working in the presence of industrial odors.

It is noteworthy that the odor counteractant was more acceptable when used at $^1/_2$ and at double the recommended rate. The use of double the recommended rate was especially successful since this was the only test for which a clear majority considered the resulting odor either "pleasant" or "not objectionable." The preference for the use of the odor counteractant at double and $^1/_2$ the recommended rate is somewhat difficult to interpret. At double the recommended rate the characteristic odor of the counteractant was clearly discernible and there was no question that the additive was behaving as an odor mask rather than as an odor counteractant. Three of the 10 subjects considered the odor of the counteractant to be just as objectionable as the odor of the untreated stack gases.

The more favorable reaction at $^1/_2$ the recommended dose rate, on the other hand, may indicate an actual decrease in the combined odor intensity and closer approach to neutralization or counteraction than was actually achieved at the recommended dose rate. Whether the output of industrial stacks ever becomes sufficiently steady to permit the application of precise amounts of odor chemicals is open to some question and the practice of applying the chemical at the point of stack discharge makes uniform mixing difficult to achieve.

A second part of the test was to estimate the amount of counteractant added to the stack by observation of the intensity and character of the odor at the test station $^1/_3$ of a mile from the plant. It was believed that this information would be useful in evaluating the odor preferences of the test panel. These data have been analyzed in 2 ways. First, whether or not a panel member could

judge the correct amount of odor counteractant and second, whether he could tell when the counteractant was "on" or "off," even though he might be unable to estimate the exact quantity in use when the counteractant was "on." It may be noted from Table II that in only 35 out of 80 chances (44%) was the panel able to estimate the exact status of the addition of the odor counteractant from an observation of the odor of the stack gases and, in fact, only 3 out of the 10 observers were able to judge correctly more than 50% of the time. The odor panel was able to attain a better score when judging whether the odor counteractant was "on" or "off." On this basis, 57 correct answers were obtained out of a possible 80 (70%). It is noteworthy that every member of the odor panel was aware of the presence of the odor counteractant when it was turned on at double the recommended rate although 4 out of the 10 observers were not able to estimate the quantity correctly.

It is interesting to evaluate the data for consistency. It has been noted already that 3 of the 10 observers found the odor of the counteractant chemicals just as unpleasant as the odor of the raw stack gases and were not satisfied with any combination of the two. Observer "D" considered the stack odor "objectionable" when he thought the addition of odor counteractant was at the normal rate and "unpleasant" when he thought it was at $^1/_2$ the normal rate; although no odor counteractant was, in fact, being added to the stack gases in either case. Thus it may be concluded that some members based their odor reaction on their estimate of the quantity of odor counteractant being placed in the stack. Others, such as observer "E," defy logical analysis: he estimated that the odor counteractant was being added at $^1/_2$ the recommended rate and that the odor was "not objectionable" when, in reality, the counteractant was turned off. In another test he estimated the addition of counteractant to be $^1/_2$ the recommended rate and he judged the odor to be "objectionable" when, in fact, the counteractant was being added at the recommended rate. Observer "H" shows similar tendencies, e.g., he reported "normal quantity of odor counteractant" and odor "unpleasant" when the chemical was actually turned off and the same reaction when the counteractant was turned on at the recommended rate.

Before discussing the conclusions which may be drawn from this study, it is desirable to examine the validity of the test method by reference to criteria established by workers in the field of odor counteraction. Arthur Goldman has the following to say regarding odor surveys[1]: "All normal people can perceive odors, and the most important method of gas analysis ever employed is the sense of smell. In the last analysis, organoleptic surveys are the criteria for the effect of an odor nuisance or the effectiveness of an odor abatement program.

"To obtain valid surveys, an odor jury is required. It is important to have at least 7 persons included in the odor jury. The observers are not necessarily required to demonstrate an unusual olfactory acuteness or discrimination to qualify for a panel. On the other hand the observers should be necessarily objective in their opinions. Technically trained laboratory personnel are excellent for the above stated reasons. The jury require a list of descriptive and easily identifiable terms in order that the description of odor will be uniform."

According to the above criteria, this odor study should qualify as an acceptable test. Nevertheless, it is desirable to recognize certain limitations. For example, the 10 members of the odor panel were all males between the ages of 20 and 45 years who were accustomed to work in and around odors of a character and intensity seldom experienced by the general population for any length of time. To some extent, at least, their reaction to foul odors would be less intense than that of the population in general.

In spite of the fact that the survey was weighted in favor of acceptance of the odor by reason of the presence on the odor panel of 9 individuals accustomed to work in this odorous atmosphere for 40 or more hrs/week, the results of the tests showed a preponderance of unfavorable reactions to the stack odor when the odor counteractant was used at the recommended dosage rate. This reaction did not differ significantly from the preferences expressed when no counteractant at all was used. Only when the odor counteractant was used in sufficient quantities to completely mask the odor of the stack gases did a majority of the odor panel consider the resultant odor not objectionable. On the basis of the data which have been summarized in the table it is difficult to sustain any case for the use of odor counteractants except as they are employed as powerful odor masking agents. As such, it is extremely doubtful that any significant portion of the general population will find the odor of the counteractant chemicals acceptable for a long period. In this connection it is interesting to note that John Von Bergen[2] agrees that "Most people object to any odor, pleasant or unpleasant, over a period time." In addition, treatment costs at double the normal rate of application would become prohibitive on any large-scale, sustained usage.

In spite of the many inadequacies of this brief study, it represents, to the best

Table II—Odor Application Ratings

Actual Rate of Application of Odor Counteractant	Observers' Estimate of Odor Counteractant Application Rate									
	A	B	C	D	E	F	G	H	I	J
Recommended rate	Twice	Half	Half	Recommended	Recommended	Half	None	Twice	None	None
None	Half	None	Half	Half	None	Recommended	None	None	None	Half
Twice recommended rate	Twice	Twice	Recommended	Twice	Half	Twice	Twice	Twice	Half	Recommended
Half recommended rate	Half	None	Twice	Half	Half	Recommended	Half	Recommended	Recommended	None
None	None	Half	None	Half	Half	Recommended	None	None	Twice	None
None	None	None	Half	Recommended	Twice	Half	None	None	None	Recommended
Recommended rate	Twice	None	Recommended	Recommended	Half	Recommended	Recommended	Recommended	None	Twice
Recommended rate	Recommended	Half	Twice	Twice	Half	Twice	Recommended	None	Half	Recommended
No. correct estimates of application rate	5	3	2	4	3	2	7	5	2	2
No. correct estimates counteractant on or off	7	5	6	5	6	5	7	7	5	4

of my knowledge, the only available objective data on the effectiveness of odor counteractants for the reodorization of stack gas effluents. It is hoped that it will stimulate the advocates of this system of stack gas treatment to perform and publish studies of a scientific nature which will demonstrate the fields of usefulness, if any, of odor counteractants and/or masking agents in air pollution control activities.

It is to be hoped that along with these studies will come satisfactory answers to a number of serious questions connected with the use of odor counteractants in stack emissions. For example, the statement was made a few years ago before the Air Pollution Control Association that "The man in the street represents public opinion and when he says, 'It stinks,' that is air pollution."[3] We may have some justifiable hesitancy about accepting this as a proper definition of air pollution but, pursuing the idea to its logical conclusion, may we assume that when the odor counteractant added to the stack effluent meets the disapproval of the men in the street, that this, also, by definition, constitutes air pollution? This same question must have troubled others because in 1956 the statement was modified to read as follows: "The man in the street represents public opinion and when he says, 'It stinks,' that is organoleptic appraisal of air pollution,"[4] (which seems to tell us that when "the man in the street" is aware of unpleasant odors he is appraising air pollution by nose).

Another aspect of the use of odor counteractants or odor masks in stack gas effluents is the legal responsibility of the plant to the general public. An unbiased appraisal of the toxicity of these materials would appear to be a necessity but one must depend on the manufacturers' assurance because the formulae are trade secrets and subject to change without notice. In addition, one would want to know whether these substances are capable of producing allergies or, when combined with natural constituents of the atmosphere, can produce allergens which may affect segments of the population.

Since these materials are supposed to interfere with the perception of odors, what about odors of a protective nature, such as odorants added to domestic gas? Is it possible that a victim of gas poisoning would have been aware of his danger in adequate time had his sense of smell not been destroyed by odor counteractants added to the stack gases of a nearby industrial plant?

Is the use of odor counteractants in stack gases equivalent to mass medication? It can be confidently predicted that large segments of the population will object to such additions to the air they breath when they fully understand the nature and purpose of the process. If we draw a parallel between air purification and water purification, we note that the objective in water works practice with respect to undesirable odors in drinking water is to eliminate them rather than to counteract them with other odors of antagonistic properties.

Answers to these, and perhaps other questions, are required prior to a recognition of odor counteractants and odor masking agents as acceptable treatment methods for stack gas effluents.

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Experiences in CONTROLLING *Atmospheric* POLLUTION *Encountered in* PHARMACEUTICAL *Manufacturing* PROCESSES*

WILLIAM C. JOHNSON, Production Engineer, The Upjohn Company, Kalamazoo, Michigan and **DR. LLOYD L. KEMPE,** Associate Professor of Chemical Engineering & Bacteriology, University of Michigan, Ann Arbor, Michigan

The ultimate objective of the ethical pharmaceutical manufacturer is to place life saving medicine in the hands of the physician in quantity, in quality, and of course, at a fair price.

To do this successfully, the pharmaceutical industry is confronted with a variety of complex manufacturing problems involving the use of intricate research and production tools. The industry has always met these problems head-on. This type of attack has resulted in the marketing of such wonder drugs as Cortisone and the antibiotics.

We have not escaped the problem of air pollution. Even with great emphasis placed on maintenance of exacting sterility conditions for manufacturing operations, our exhaust stacks can contribute to air pollution. Generally, the problem concerns odor abatement rather than elimination of particulate matter or toxic contaminants. This paper will outline odor problems encountered in the manufacture of certain antibiotics and an antiblood coagulant, as well as those arising from anaerobic liquid waste digestion, and certain phases of our waste treatment facilities. Evaluation of the character and extent of odor problems created by these processes has been carried on simultaneously with a study of the sources of such odors, and, of some of the methods available for their elimination or reduction to minimum levels.

Before detailing the individual problems, we should like to acquaint you with our main manufacturing plant, located south of the city of Kalamazoo, Michigan. Figs. 1 and 2 are aerial views of the site. I shall point out the major buildings and specific areas which constitute the principal possible odor sources at this site; namely, (1) the Antibiotics plant, and, (2) the "swamp." Fig. 3 is an aerial view of our waste treatment facilities located west of the main plant. This constitutes the third potential odor source.

Assessment of the Problem

Odors can be caused by very small quantities of substances in the air and are often noticeable for only short intervals of time. Therefore, the best available method for determining their presence, quality, and extent is still the sensory reactions of people in the neighborhood. With this fact in mind, an odor reporting system was established using employees of The Upjohn Co. as observers. Nineteen such observers were selected from a list supplied by the Personnel Department. Several factors were considered in their selection. Among these were the location of the observers' homes with respect to proximity and direction from the plant, directions of prevailing winds, number of homes in particular areas, and the presence of neighbors who had previously complained to The Upjohn Co. about undesirable odors coming from the plant. A standard reporting form (Fig. 4) was provided for these observers along with a request to forward completed reports to the engineering office.

Once the reporting system began to operate, the reports were sorted, filed and correlated with weather data obtained from the nearby Lake Central Airlines' weather station at the Kalamazoo Municipal Airport (Fig. 5). The coded symbols were finally recorded on overlays placed on a large scale map of the area surrounding the plant (Fig. 6). During the course of this investigation, overlays were developed for use in evaluating the information accumulated (Fig. 7). A summary was then prepared for definite periods of reports (Fig. 8).

A. Two general types of odors were identified. These were a sewage and a musty-sour odor.

B. Sewage odor reports came from the following areas:

1. One mi north of the north part of the swamp.
2. One-half mi south and southwest of the north part of the swamp.
3. One-half mi west of the waste treatment plant.
4. One-quarter to $^1/_2$ mi north-northwest and northeast of the waste treatment plant.

C. Musty odors were reported only from people located approximately $^3/_4$ of a mi north-northwest and a similar distance northeast of the antibiotics building; however, almost all the reports of this type of odor came from the first mentioned area.

D. Sewage odor complaints were generally reported for the evening, night or early morning hours. However, musty odors were reported for almost any time of the day or night.

E. Hot, cloudy nights, during which there was little or no wind, resulted in the greatest number of complaints of sewage odor. These complaints were particularly numerous until the flumes (covered later in this paper) were installed in the swamp.

F. The odor complaints and reports combined with weather data indicated at least three major sources of odor at the plant; these were the swamp, the antibiotics manufacturing area, and the waste treatment plant. Observa-

* Presented at 51st Annual Meeting of APCA, May 25–29, 1958 at Philadelphia.

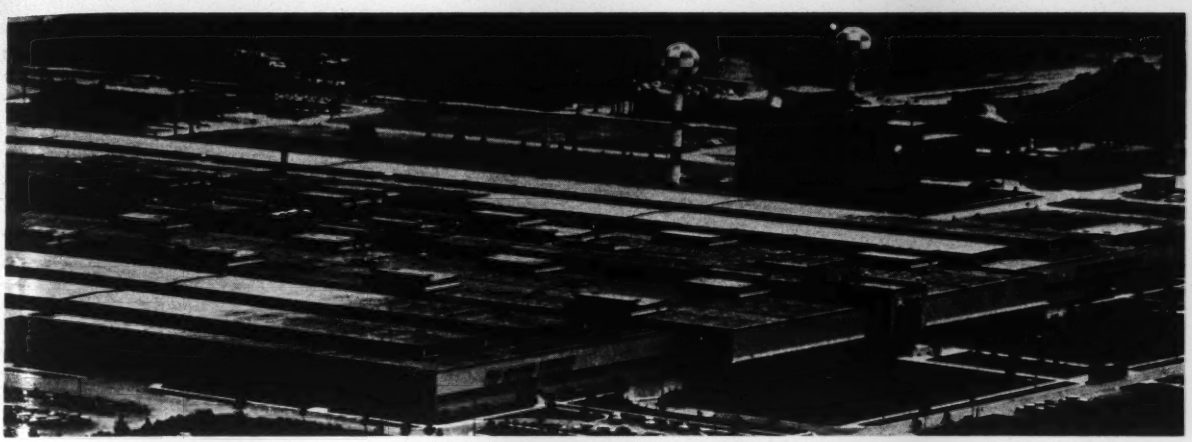


Fig. 1.

tions also established the power plant as a more or less continuous odor producer, while several incinerators in Building 41 and in the swamp area occasionally contributed odors (Fig. 9).

G. Reports from Stations 2, 13, and 18 confirmed the presence of odors meriting complaint by certain neighbors.

H. The reporting and analysis system permitted continual evaluation of the odor problems at the plant. Consequently, continuation of the analysis helps to evaluate the effects of corrective measures and also the development of any new odor sources.

Antibiotics Manufacturing

Antibiotics production is centered in a modern building separated from the main manufacturing plant. Strong, stifling odors originate from these processes on some occasions, while during other periods there is little or no odor produced. The odors are peculiar and carry for long distances; hence, they are easily identified by neighbors in the area. In addition, the odors seem to be strongest on hot summer nights and weekends which make the odors particularly repugnant.

The odors develop from three main sources; namely, vent gases from the fermentors, spilled "beers" and filter cake, and vapors from the waste aeration tank. The vent gases from erythromycin production, for example, are objectionable.

A qualitative test, using an apparatus supplied by the W. B. Connor Co., demonstrated that the odors from this source can be completely adsorbed by activated carbon. Accordingly, a pilot test unit was designed and built in our shops wherein 100 cfm of odorous vent gas under slight pressure and at 80°F was passed through a manifold of activated carbon cannisters. Results were satisfactory and analysis of the carbon showed that this air contained 0.32 lbs odiferous substance/million cu ft of air. On the basis of both laboratory and pilot testing, a collection manifold system was designed and constructed.

This system collects all vent gases, scrubs them in a Trane evaporator cooler equipped with an entrainment separator, and discharges the scrubbed gases through a series of activated carbon panels. The "scrubber" used is a piece of equipment that had been previously installed for another purpose, and was adapted to the odor collection system. It offers wide flexibility in the choice of scrubbing media for removal of soluble odors, thereby increasing the life of the carbon.

A second problem in conjunction with that of odor was the distinct possibility of contamination of our compressor air intake by these vent gases. Deep vat fermentations are carried out under rigid conditions of sterility. The peculiarities of atmospheric conditions in the area were ideal for blowing exhaust vent gases into the air intake stack. Our collection system discharges the treated air some distance away from the air intake.

Figs. 10 and 11 show the roof area of the Antibiotics plant, the vent stacks and the location of the air intake stack. Fig. 10 illustrates the distinct possibility of air contamination which existed.

By constant attention to housekeeping, odors arising from spillages have been reduced to a minimum. Judicial use of the waste aeration tank has reduced the odors from this source.

Swamp

A swampy area, approximately 100 ac in extent, covers the southeastern section of the Portage Road plant site. The discharge of wastes into a small area at the northwest corner of the swamp caused anaerobic conditions to develop in the water. In addition, the bottom deposits were actively undergoing anaerobic decomposition. As a consequence this small portion of the northwest corner of the swamp was producing large amounts of gases having a sweet, sickening odor, floating sludge mats, and generally disagreeable conditions. The odors developed were sufficiently strong to be reported by persons who live approximately 1 mi north of this portion of the swamp. However, an examination of the rest of the swamp indicated that it was relatively unpolluted. This suggested that, probably because the swamp was very shallow and overgrown with aquatic plants, only a very small part of the swamp was being used to oxidize these wastes. Consideration of this observation suggested that the swamp might be able to oxidize all the wastes then discharged into it and still not become anaerobic if (1) the wastes were distributed into a larger area of the swamp, and (2) fresh water was introduced during the night and over the weekends into areas that were beginning to become anaerobic. Accordingly, there were designed and installed, a network of three flumes originating in a head box which was

Fig. 2.

Fig. 3.

ODOR REPORT

Station no.____

Odor Description: (underline where indicated)

Musty Sewage Sharp Other (describe)

_____

_____

_____

Usual Different (than usually observed)
Very strong Strong Moderate Faint
Persistent Comes & goes

Place Observed:

Home Other (describe)

Time Observed:

Date_____ Hours: From_____ To_____

Wind Direction: (from) N - NW - W - SW - S - SE - E - NE

Atmospheric Conditions: Cloudy Rain Fog

Amount of Wind: Strong Moderate Slight None

Remarks: _____

_____

_____

_____

Please return: L.L.Kempe, Dept. 57-41-1

Signed_____

Fig. 4.

located near the outlet of the south drainage ditch (Fig. 12). These flumes permitted wastes to be fairly uniformly distributed over approximately 30 ac of the swamp during the working day.

Throughout the night, relatively clear water originating from cooling water, well water, and "storm water," was conducted through the flumes into areas that were either anaerobic or becoming anaerobic.

Regular observations during the summer of 1953 indicated the following:

1. Odor reports and complaints involving offensive conditions at the swamp almost completely stopped since the flumes went into full operation.
2. The putrid, offensive area of the swamp on the northwest corner recovered to a relatively clean condition.

Waste Treatment Plant

The waste treatment plant (Fig. 3) is located about 1/4 of a mi due west of the Portage Road plant and also within a quarter of a mile of residences in several directions. It constitutes one source of odor from company operations at the Portage Road site. It consists of primary settling tanks, trickling filters, final settling tanks, and a chlorinating unit. Part of the settled solids removed in the settling tanks is anaerobically treated in a sludge digester.

In general, odors from the waste treatment plant are not pronounced, being about what would be expected. Some odors are continuously present, such as those resulting from spraying the wastes on the trickling filters. Since the filters are not housed, slight breezes accentuate the amount of odors developed and carry them in a relatively undiluted form. Some odor will always be found around any waste treatment plant; however, if the wastes are prevented from becoming anaerobic during preliminary settling, etc., the odors should not be particularly strong. Suitable landscaping of the area with trees and bushes that would restrict and deflect slight breezes from the trickling filters might reduce the amount of odors coming from the plant.

Settled solids are digested anaerobically. The gases from this process have a very foul odor. However, when properly oxidized in a suitable burner, the resultant odors are negligible. Nevertheless, the presence of an anaerobic process at the waste treatment plant presents a potential odor source such as may occur when the waste gas burner does not operate properly or when digested solids are pumped from the digester. A conscious effort is always made to operate this plant with a

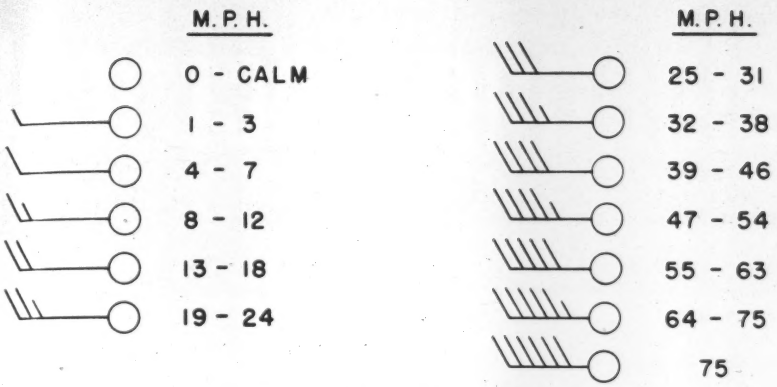


Fig. 5. Beaufort scale of wind force.

maximum efficiency and a minimum of odor. This procedure is resulting in a low odor level in the surrounding area so no accessory odor abatement equipment has become necessary.

Estrogen Plant

Additional manufacturing facilities are maintained by the Company. Our fourth major odor offender was the Estrogen plant located northwest of the city (Fig. 13).

Extremely malodorous fumes were given off from the processing of beef lung in the manufacture of Heparin, one of the antiblood coagulants. The process requirements were such that these odors were unavoidable so only minor process changes were possible.

However, equipment changes were made in many instances. For example; wherever possible, open-type equipment was tightly enclosed. This procedure allowed a substantial reduction in the amount of exhaust air that needed subsequent treatment. In addition, rigid housekeeping procedures were used, and adequate storage facilities for raw materials were provided.

Since no previous experience was available to guide us in controlling the odors produced, laboratory experiments were conducted on odorous vent gases using simple glass apparatus. A variety of absorbing solutions such as caustic and acid as well as oxidizing and reducing substances were evaluated. Finally hypochlorite solutions containing 5 to 70% available chlorine were tried and found to be effective in absorbing the odors.

Experiments were also conducted using several materials as adsorbents. Among those used were activated carbon, silica gel, and slaked lime. Activated carbon was successful in removing the odors; silica gel and lime were only partially suitable.

Condensation of the odorous material in a freeze-trap, though successful, was not considered to represent a feasible economic solution to the problem.

Transformation of the odor by catalytic incineration was also used successfully on a laboratory scale.

Here then was a problem with at least three possible solutions by three different methods; namely, (1) absorption in chlorine, (2) adsorption on activated carbon, and (3) transformation by catalytic combustion. As an aid in reducing the amount of odor, some modification of existing process equipment was also possible. Selection among these three methods depended upon cost and upon the speed with which the method could be applied. Preliminary pilot tests conducted with activated carbon and catalytic incineration indicated higher maintenance costs than expected for the chlorine treatment. Consequently the latter was deemed to be the best starting point for large scale work.

Because of the severe corrosiveness of wet chlorine, it was necessary to fabricate absorption equipment from materials resistant to chemical attack. Usually such materials are costly, the Hastelloy alloys being an example. Therefore, central collection equipment made from such materials was not considered feasible in view of the unknown efficiencies to be obtained by treatment of the odor with chlorine bearing solutions. Instead a standard air washer, made of steel, was purchased and coated with a phenolic resin. The washer consisted of a chamber designed in such a way that the entering air passed through the spray from a series of nozzles. These nozzles were mounted on headers and provided a definite spray pattern that developed a completely wetted interior surface. The solution fell to a collection chamber at the bottom of the washer and was recirculated to the nozzles by a pump. Eliminator plates at the exit end of the box prevented a large carryover of moisture in the exhaust air. Air was circulated by an exhaust fan mounted on the exit side of the washer. The air discharge was connected to a vertical stack that extended through the roof to a height sufficient for prevailing winds to disseminate and dilute the effluent stack gas. Regulation of makeup water volume admitted into the chamber was accomplished by means of a float valve.

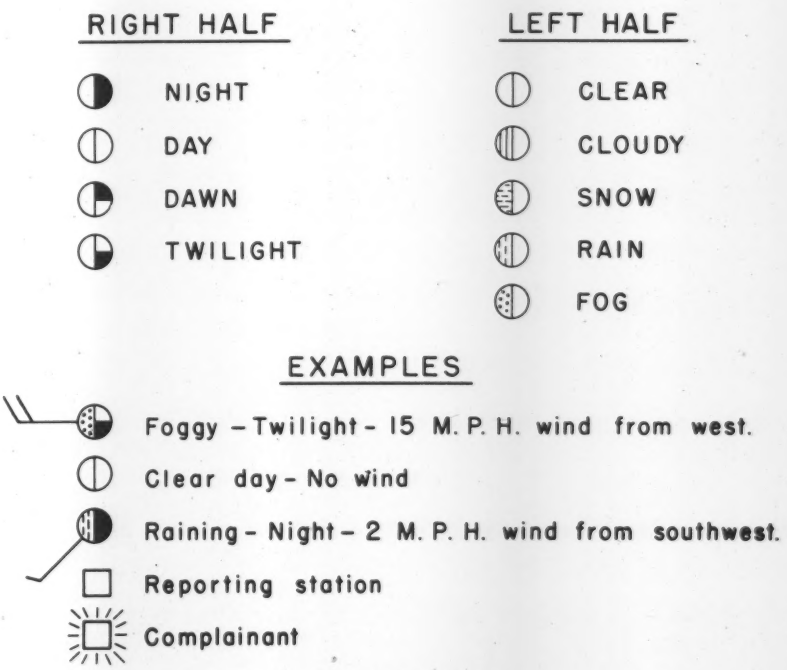
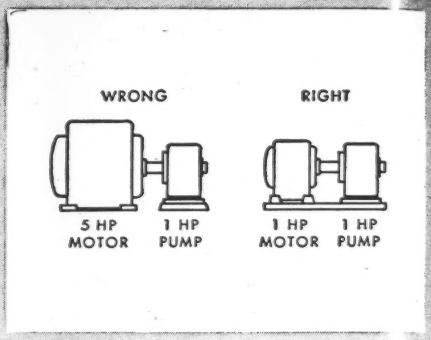


Fig. 6. Meteorological code.

Tips on evaluating Electrical

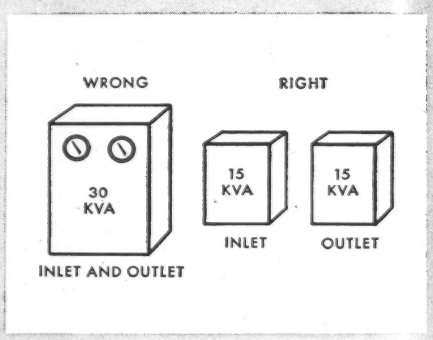
Matched Electrical Sets

You wouldn't use a 5 h.p. motor to run a pump that required only one h.p. Similarly, electrical sets should be *matched* to the requirements of the specific job. Electrical sets should be sized according to gas conditions, dust conditions, and other operating characteristics, and in accord with manufacturers' past experience on similar installations. *Don't be misled by high KVA ratings on the electrical sets.* The precipitator will only absorb a certain amount of power and the sets should be sized accordingly. A large excess of installed power, which will never be used, means inefficient use of the equipment.



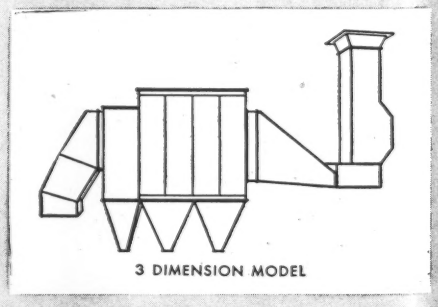
Varied Electrical Conditions

Electrical conditions in a precipitator can vary widely at different parts of the precipitator. For instance, a high voltage, low current condition usually prevails at the inlet where the dust load is high, as compared to a lower voltage higher current condition at the outlet. Consequently, it is good design (and a necessity for high efficiency) to furnish several electrical sections in series, with energization from separate electrical sets so that each section can be adjusted to best suit the conditions.



Gas Distribution

Remember that gas distribution, gas baffling, and provision against hopper sweeping all have a large influence on collection efficiency. The gas flow system should be analyzed as closely as possible, both in the precipitator and in the associated ductwork. If in doubt, have a three-dimensional gas flow study made. Two-dimensional gas flow studies *are not as accurate* and may lead to erroneous conclusions.



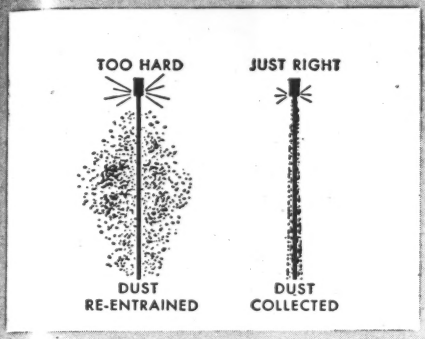
RESEARCH

RESEARCH-COTTRELL, INC. Main Office and Plant: Bound Brook, New Jersey

IC 191

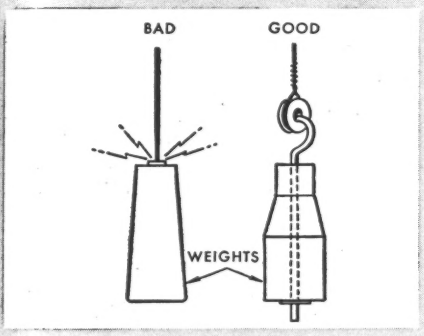
Precipitators

Some helpful hints to aid in selecting a properly designed unit



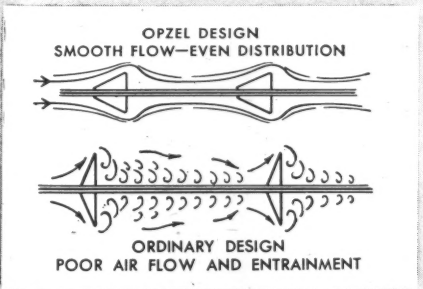
Rapping Intensity

Rappers should have easy means to vary the intensity of the blow to suit variations in operating conditions. A pre-set intensity setting cannot possibly give proper rapping over the normal range of operation. If too soft, build-up will occur which will disturb electrical conditions. If too hard, there will be reentrainment. Means of intensity adjustment are necessary to avoid drop-off of precipitator efficiency as conditions change.



Corona Discharge

It is a relatively easy matter to obtain a corona discharge in an electrostatic precipitator. Many types of discharge electrodes have been used over the past forty years, including ribbons, squares, twisted squares, star shaped sections, coiled wires, wires with prongs and projections, most of which give entirely adequate corona conditions. Final choice then gets down to mechanical factors such as strength of wire, method of support to avoid stress points, and ease of handling. There are many claims made for various types of wires but after investigating and testing hundreds of different kinds, we find a straight round wire about .1″ diameter to be best.



Baffle Design

Careful attention to the design of baffles on the collecting plates is most important. Small amounts of reentrainment mean tremendous differences in over-all collection efficiencies. It is seen that the "quality" of the collecting surface is far more important than quantity — quantity (sq. ft. of surface or treatment time) in itself is not a criterion of performance.

-COTTRELL

Representatives in all major cities of U.S. and Canada

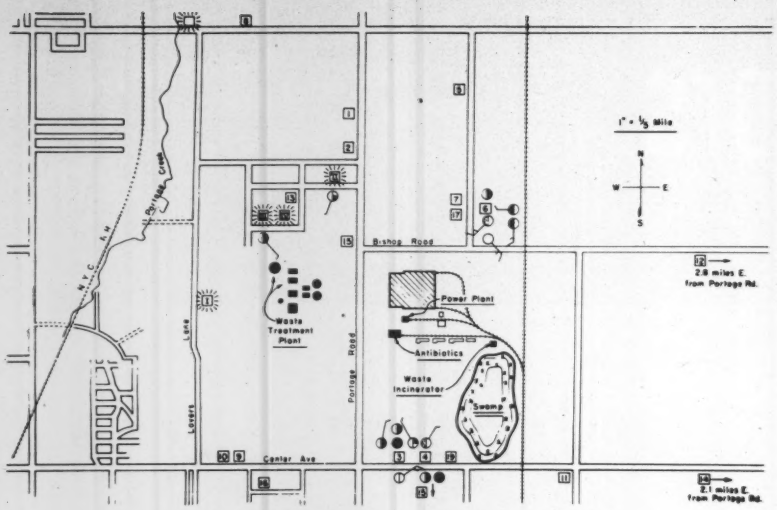


Fig. 7. Recorded odor complaints up to June 30, 1953.

Laboratory tests established the fact that a solution containing approximately 20–50 ppm chlorine was sufficient to absorb the odors. Accordingly, a plastic feed device was installed on the makeup water line to provide a chlorine concentration in this range at all times. However, the chlorine was utilized so rapidly by the 8000 cfm of odor bearing inlet air that the feed device was overloaded. Consequently, the automatic feed system was abandoned and manual control was attempted. This was only partially acceptable. It had the obvious disadvantage of not allowing for 24-hr operation.

Various deodorant products introduced into the spray were also tried. These were again only partially successful. It was then thought that a combination of plain water spray followed by application of chlorine gas from a direct feed chlorinator would be more suitable. This procedure was followed. A standard chlorinator unit was installed and chlorine gas was metered to the exit side of the washing chamber. Extra-heavy, genuine wrought iron pipe was used to convey the gas and a silver sparging tube was inserted into the chamber. Results were good. However, corrosion of the fan, stack, and washer was severe so the galvanized stack was replaced with one made of transite. This stack was satisfactory except for the metal fasteners used in its fabrication, which corroded.

To treat 8000 cfm of air for 24 hrs, approximately 25 lbs of chlorine was necessary. When compared with hypochlorite solutions, the use of chlorine gas represented a fivefold cost reduction.

The solution to the problem by chlorination proved successful even though the original scrubbing equipment suffered severely from corrosion. Before a redesign of the chlorine system was undertaken, adsorption of the malodorous air on activated carbon was again considered. Earlier results had indicated a high maintenance cost.

An activated carbon test unit was installed on the exit side of our collection system. This unit consisted of four 1.5# cannisters mounted on a suitable manifold plate. One hundred cfm of

STA. No.	ODOR OBSER.	ODOR LEVEL	DATE	TIME (24 hr. clock)	WIND DIR.	SPEED M.P.H.	ATMOS. COND.	REMARKS
2	Musty	Mod.	7-11-53	0300-0400	SSE	1	Clear	First time noticed in several weeks. Same odor as notice when driving by building 38.
3	Sewage	Strong	6-23-53	2100	N	2	Cloudy	The usual swamp odor.
4	Sewage	Very strong	7-18-53	All night		0	Cloudy	Getting worse!
4	Sewage-Sharp	Very strong	7-21-53	All night	WNW	0-3	Cloudy	Getting sharp odor along with sewage odor.
4	Sewage	Mod. to Faint		Night		0	Cloudy	Not a persistent odor like it had previously been.
6	Putrid-Sewage	Strong	6-15-53	1730	SSE	11	Clear	Swamp at fault.
17	Sewage	Strong	7-20-53	2200-0800		0	Cloudy	Says wind was in the south on 7-19 & 7-20.
I			7-15-53	Night	E	8	Cloudy	Wind became calm at 2200. Makes her sick, bites her face, gives her headache. Said wind was from direction of disposal plant.
II	Musty & putrid odor from WTP	Very strong	6-25-53	2030-2100	SW	9	Cloudy	Week ends are particularly bad, combined with low ceiling.
II	Fertilizer	Very strong	7-29-53	1815	WNW	5	Cloudy	Says wind was from N(?). Actually it was SW most of the afternoon until 1600 (approx.).
III	Rotten eggs.		5-19-53	2000		0	Clear	

Fig. 8. Summary of odor observations received correlated with meteorological data.

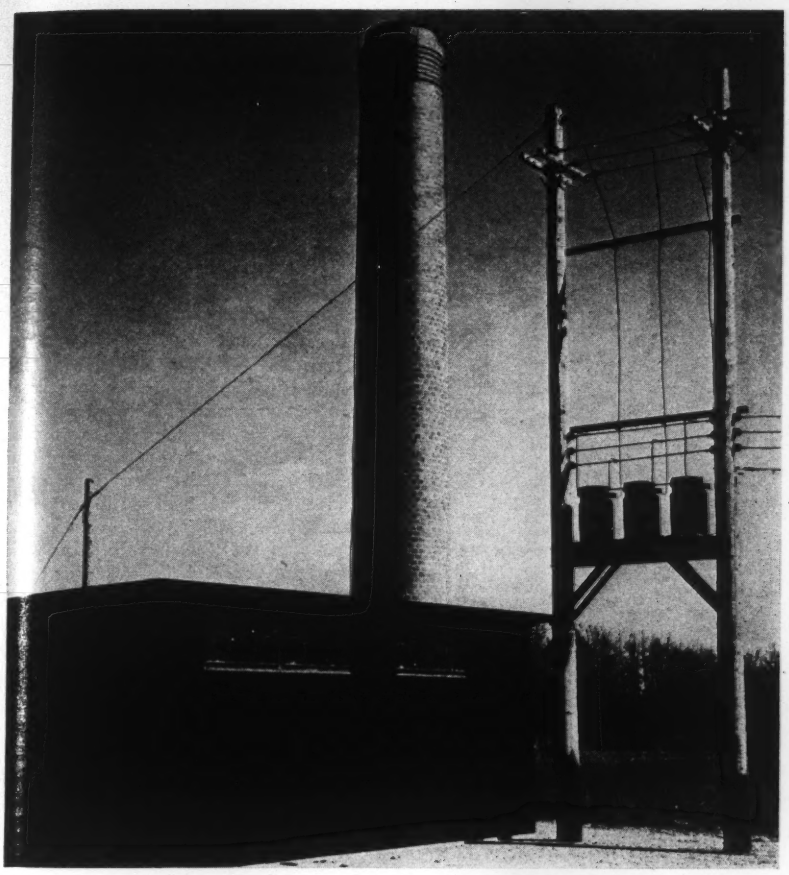


Fig. 9.

untreated exhaust stack gas was metered through the unit on a 24-hr day basis. The unit operated for a 2-wk period, with constant checks being made for a threshold odor breakthrough. The first indication of such breakthrough occurred during the sixth day of the test with a complete breakthrough developing in 9 days. The cannisters were returned to the manufacturer for analysis whose test indicated an expected life of 7.6 days. This closely checked the olfactory test results which had indicated an odor breakthrough sometime between the 6th and 9th days.

On this basis, 320, $1^1/_2$# cannisters would be needed for 8000 cfm malodorous air. In addition, they would require regeneration every week. Consequently the costs would be higher than those previously found for chlorine treatment; so, even though this method of odor removal was completely effective, it was considered too costly for this case.

We next considered transformation of the malodorous fumes by catalytic incineration. A test unit, capable of handling 20 cfm air at 70°F was installed on the exit side of the central collection chamber. Insofar as we are aware, this trial constituted one of the first industrial tests of this type of equipment on a pharmaceutical manufacturing odor problem.

Briefly, the unit operates on the following principle[1]:

> *"Catalyst Element:* In application, the catalyst element has the appearance of a metallic air filter mat. The construction is intended to provide a high catalyst surface exposure, turbulence in passage through the element and low resistance to flow. The chemical union of oxygen and hydrocarbons occurs without flame on the surface of the catalyst. Heat generated by incineration is transmitted to the air stream, causing an abrupt rise in temperature. The temperature rise occurs in direct relation to the potential energy content of the fume-air mixture.
>
> For example, if the mixture entering the catalyst contains energy equivalent of 1 BTU/cu ft at 500°F, the catalyst discharge temperature will be raised to slightly over 600°F. With such a low fume concentration there will be no visible evidence of combustion on the catalyst. However, with energy concentrations of 5 BTU/cu ft or more, which are uncommon in many industrial stack fumes, the resultant temperature rise will cause the catalyst to develop a red glow. Sustained discharge temperatures above 1200°F are permissible without damage to the catalyst.
>
> Initial Ignition Requirements: To cause initial ignition of the fumes on the catalyst, an entry temperature of approximately 500°F is required, although this initial ignition temperature will vary depending on the nature of the fumes. In any event, once catalytic combustion has been established, the process can be sustained thereafter with reduced air entry temperature. Combustion sustaining temperatures at the entry side of the catalyst vary inversely with the fume concentration, so that incineration can be maintained with 70°F fume entry temperature providing the energy concentration equivalent is at least 15 BTU/cu ft.
>
> Clogging or Poisoning of Catalyst Element: Use of the catalyst is

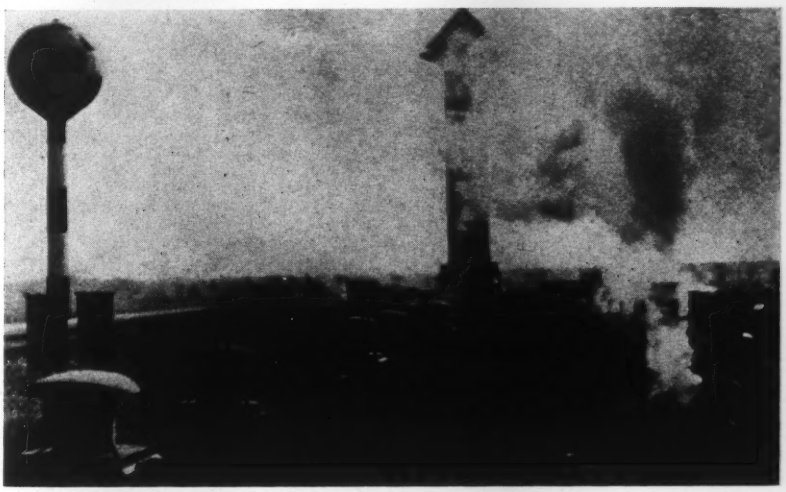


Fig. 10.

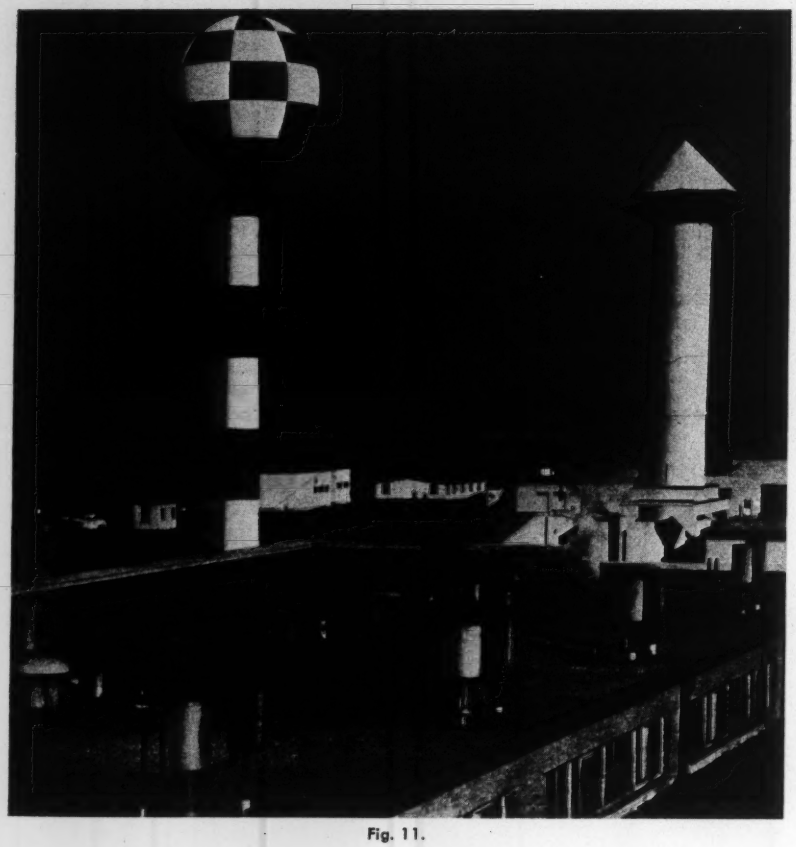


Fig. 11.

limited to fumes substantially free of unburnable solids. While μ size particles will pass through the element, fumes containing large quantities of cinders or abrasives cause clogging and failure in a short time. Vapors of the metallic group which have a high vapor pressure, such as mercury and zinc, will cause "poisoning" or deactivation of the catalyst. These metals rarely occur with mixtures of hydrocarbons, but whenever present, catalytic incineration is not recommended."

Our test data indicated that approximately 5 to 9 gal of #2 oil/hr would be required to raise the temperature of the incoming gas to 480°F from which point the catalyst would take over. On this basis, fuel cost was high. Consequently, this method was abandoned even though it successfully removed the odors.

The next step was to re-engineer the chlorine method of treatment so as to combat corrosion. This was done, although the final design represented a compromise over the original intent. A 12-in. Haveg 60 fume scrubber was ordered to be used both for the mixing chamber and as the air prime mover.

Because delay was expected in receiving the scrubber and due to the imminent possibility of other equipment failure, a phenolic coated exhaust fan was substituted. As finally constructed our air collection and treatment system consisted of a wooden spray tank, wood stack, phenolic coated fan, and a recirculating pump. Cl_2 gas is fed directly to the stack where it contacts the water scrubbed gas. Results have been completely satisfactory (Fig. 14).

Fig. 12.

Conclusion

We have described some of the problems in air pollution associated with the pharmaceutical industry. Generally, costs for odor abatement are overhead costs which cause higher production costs. An enlightened management is needed to accept these higher costs in the interest of the community welfare. It should not be the neighbor who first tells you that an odor problem exists. However, should this happen and legal force be brought to bear, every effort should be expended toward reducing or eliminating the problem. To do this, not only is technical assistance necessary, but the very closest kind of co-operation between local and state government officials and enforcing agencies is essential. A public relations program of merit is a continuing program long after specific problems are solved.

This kind of program is one which we, in the pharmaceutical industry, try to follow.

Summary

A planned, co-ordinated approach to the evaluation of odor sources from antibiotics manufacturing process has been presented. This approach included development of an odor reporting network, correlation of the network data with weather information, coding and recording on a map overlay, and finally evaluation of the information.

Attack on the odor problems found from the survey included laboratory investigation, pilot model studies, process modification, and plant installation of control equipment.

Antibiotic fermentation vent gas odors were eliminated with activated

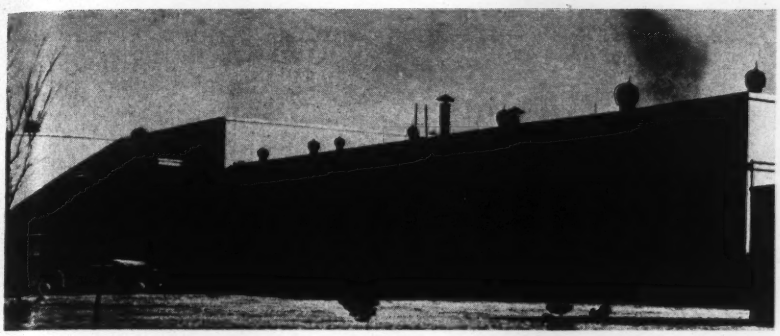


Fig. 13.

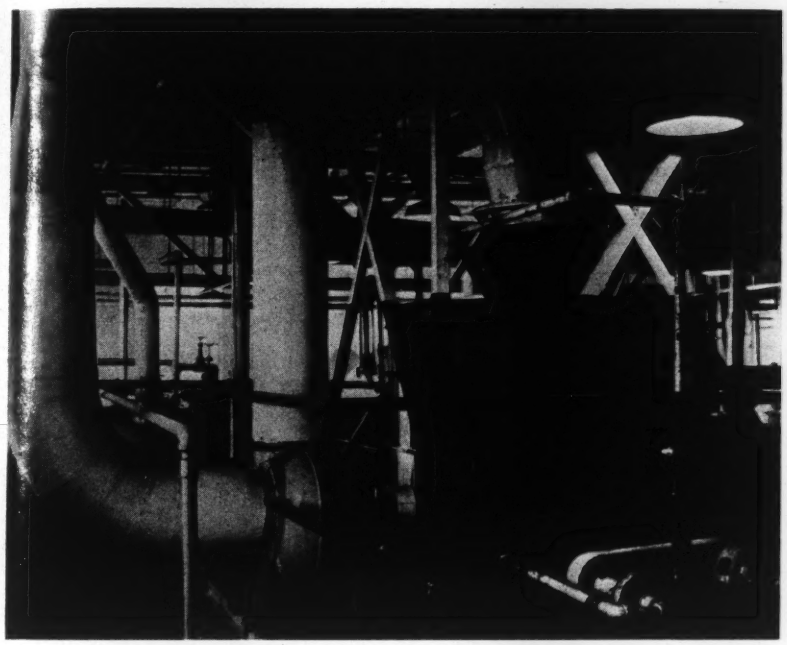


Fig. 14.

carbon. Putrid odors from a polluted swamp were controlled through conversion of the swamp to an oxidation pond, and odors from Heparin manufacture were controlled by absorption in chlorinated water.

Since process changes are common procedure in the pharmaceutical manufacturing industry, a continuing odor control program is essential to maintenance of good relations with plant neighbors. In addition, a public relations program directed toward acquainting all concerned with efforts being made to control odors along with some of the problems involved, pays dividends in community tolerance of minimum odor levels that may defy elimination.

REFERENCE

1. R. J. Ruff, President, Catalytic Combustion Corporation, Detroit, Michigan.

MEASUREMENT of OZONE Concentration

JOHN H. HORWOOD, Department of Physiological Hygiene, University of Toronto

In an investigation of the composition of the atmosphere, whether it be inside or outdoor atmosphere, it is sometimes desirable to have data concerning the concentration of ozone. For this purpose Bradley and Haagen-Smit[1] have developed a technique which makes use of the cracking which develops in a small folded strip of specially compounded rubber in an atmosphere containing ozone. In accordance with the method of Bradley and Haagen-Smit, rubber strips 8 mm by 50 mm are folded once and the fold maintained by fastening the 2 ends together with a loop of wire. Upon exposure to an atmosphere containing ozone, cracks develop in the folded area. The extent of cracking is a function of the concentration of ozone. It can be appreciated that exposure in the manner described is simple and inexpensive, but does not provide an opportunity to determine when periods of peak concentration of ozone occur unless the rubber strip is examined frequently. The present paper describes the construction of an inexpensive piece of equipment, an ozonometer, which will show, over a period of 1 or 2 days, times of elevated concentration of ozone.

The ozonometer (Fig. 1) consists of an airtight box 9 in. x 9 in. x 12 in. with an inlet tube for the air to be examined and an outlet tube for connection to a small pump or aspirator. The box contains, as shown in Fig. 2, a 36-hr clock mechanism (A) with a relative humidity recording chart 100 mm in diam. (Bristol humidograph chart no. 4043 is suitable.) The chart is intended to show relative humidity as 20%, 30%, 40%, etc. In this paper we refer to a 10% change as a movement of the recording pen from, say the 30% line to the 40% line. The chart may be viewed through a window in the box. Part B is a two-piece tube (measuring 8 in. between the clamps) containing a strip, $^1/_{16}$ in. x $^1/_{16}$ in. x 8 in. of specially compounded rubber (Goodyear Tire and Rubber Co., Inc., Akron, Ohio). This 8-inch strip is attached under constant tension by wire and clamp to each end of the tube so that $2^1/_2$ inches of relaxed rubber is left beyond the clamp, the remaining $5^1/_2$ in. being stretched to be contained within the 8-in. tube length.

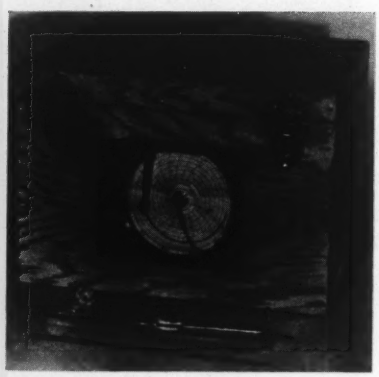


Fig. 1. Ozonometer.

This constant tension can also be obtained with the rubber strip over a pulley stretched with a 200-gram weight, Fig. 2, and then clamped. One end of the tube[1] is glass; the other end[2] is brass having a lining of rubber to serve as an ozone absorber. The recording lever of the clock mechanism is connected to the rubber strip near its midpoint. The flow of air is over the section of rubber in the glass tube and out at the mid-point strip in the brass tube. This portion of the strip, therefore, serves as a control. In the presence of air containing ozone, cracks develop in portion 1 of the rubber—but not in portion 2—so that there is movement of that part of the rubber to which the recorder is attached.

Calibration

The ozonometer was calibrated, in a dark room where interference with ozone in the air was negligible, by use of an ozone lamp (General Electric) and chemical determinations. The ozone lamp was placed in an open 2-1 flask. The air inlet tube was inserted in the neck of the flask and air was drawn through the instrument box by a small vacuum pump at 2 l/min. Ozone emission was varied by applying opaque adhesive tape to the lamp as suggested by Bradley and Haagen-Smit. The uncovered area of the lamp was found to bear a linear relationship to the ozone concentration, Graph 1.

For determination of ozone the method described by Jacobs[2] was used. The air was bubbled through 10 cc of potassium iodide solution. Iodine was then determined by titration with 0.001 N sodium thiosulphate solution.

The ozonometer was tested in atmospheres containing from about 4.4 ozone pphm of air to about 65 pphm v/v.

The time required for a 10% change on the chart in the presence of various concentrations of ozone is shown in Table 1, and plotted on double log paper, Graph 2.

Investigation was continued in an effort to establish the effect of varied conditions on deflection time, and the accuracy of a second period of deflection determination with the same rubber strip after exposure to ozone free air.

It was found that the rubber, in the presence of ozone, having lost some elasticity, takes longer to show the second 10% deflection than the first. An estimation based, therefore, on the second time would give a lower concentration than the value derived by reference to the calibration graph, which was based on the first 10% deflection at each level. In ozone-free air the record is maintained without deflection.

Reduction of the cross-sectional area of the rubber strip increased the sepsitivity so that at the 14 pphm level, 0.026

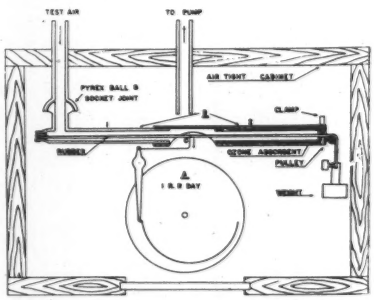
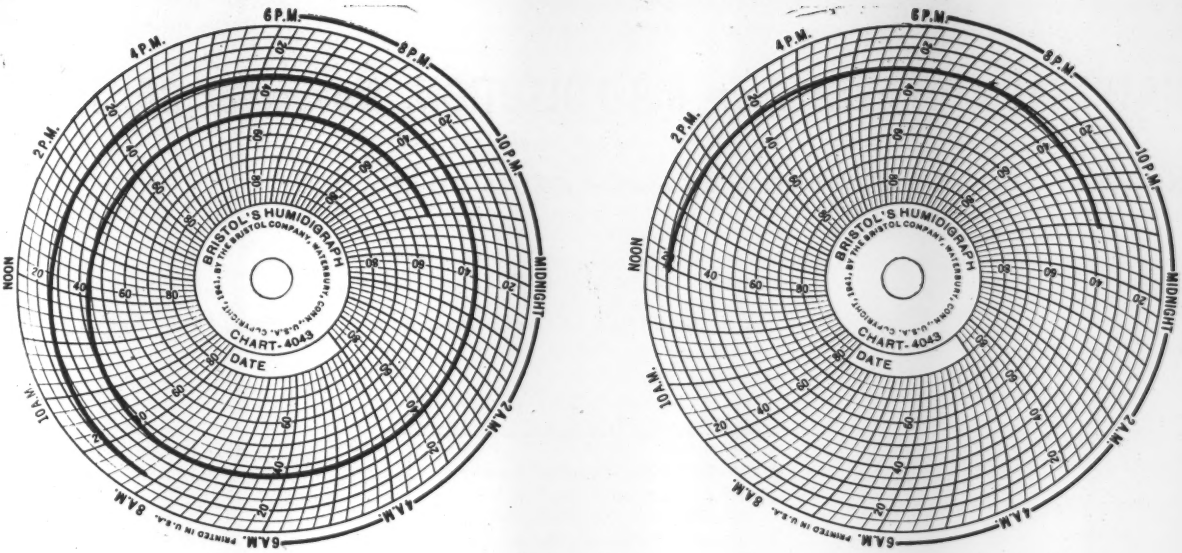


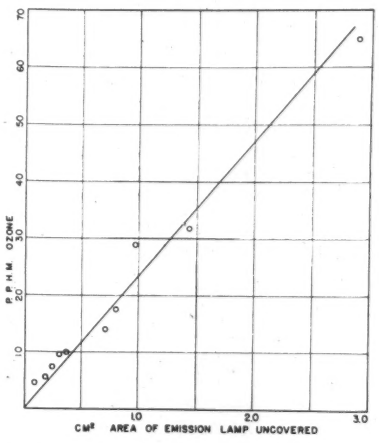
Fig. 2. Ozonometer mechanism.



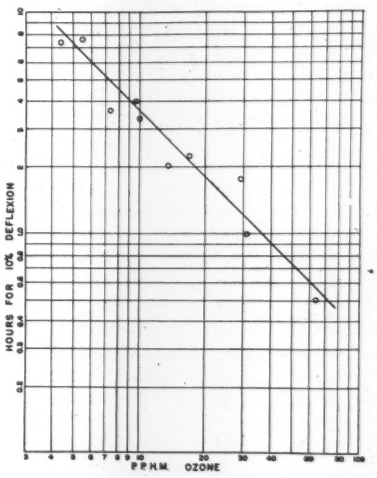
Sample Charts: A. Toronto Atmosphere, May 23–24, 1958. Showing maximum concentration in a day-time sunlight of May 23rd, followed by negligible ozone action 8 P.M.–8 A.M. with another rise in concentration until 4 P.M. May 24th. B. Calibration Chart—4.4 pphm.

Table I

Exposed Area of Lamp, Sq Cm	O_3, Pphm $\frac{v}{v}$	Time for 10% Change on Chart, Hrs	O_3, Conc x Hrs
0.09	4.4	7.5	33.0
0.18	5.5	7.75	42.3
0.24	7.3	3.75	27.3
0.30	9.7	4.0	38.6
0.36	10.0	3.3	33.2
0.72	13.8	2.0	27.6
0.80	17.6	2.25	42.3
0.96	29.2	1.8	52.5
1.44	31.8	1.0	31.8
2.88	64.9	0.5	32.5



Graph 1.



Graph 2.

in. x 0.062 in. instead of 0.062 in. x 0.062 in. changes 10% in 1 hr instead of in 2 hr.

Deviations from the line in our determinations are thought to be primarily due to difficulty in accurately obtaining a constant cross-sectional area in our rubber strip.

Acknowledgment

Grateful acknowledgment is given to Dr. A. M. Fisher for his support and advice in this project, and to Miss Helen Christie for the ozone determinations.

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2. M. B. Jacobs. *Chemical Analysis*, 1, Poisons, Hazards, Solvents, 2nd Ed., p. 369. Interscience, New York (1949).

NATIONAL CONFERENCE *on* AIR POLLUTION, *November 20, 1958*

Reports and recommendations of discussion groups

U. S. Department of Health, Education, and Welfare, Public Health Service

The APCA News has given considerable publicity to the National Conference on Air Pollution which was conducted by Public Health Service in Washington November 18 to 20.

Many APCA members attended this meeting and a considerable number took active parts either as speakers or as members of the individual panels or discussion groups.

The heart of the conference was in the work of the 6 discussion groups. With the approval of Public Health Service, the reports of the findings and recommendations of each of these groups appears in this issue of the APCA Journal. These reports were read by the chairman of each group at the Plenary Session which was held on the last day of the conference.

The purpose in printing these reports is to acquaint all APCA members with the main points of the discussions. In publishing them, neither APCA as an association nor your editor are indicating approval or disapproval of any of the statements or recommendations which are contained therein.

Discussion Group "A" Extent of Air Pollution

Report and Recommendations

IA. Where do we stand in our knowledge of

(1) The identity and quantity of pollutants in community atmospheres?

This question is concerned with our ability to apply quantitative measures to pollutants in the atmosphere, rather than to how effectively this ability has been applied to measurements across the nation. The group of discussants devoted its principal attention to problems concerned with man-made pollutants of a chemical nature rather than with airborne bacteria, pollens, and similar viable pollutants of natural origin. They recognize, however, that these latter pose important problems that need further consideration.

In identifying and measuring general classes of man-made pollutants, knowledge and techniques are available for studying almost any situation which has been found to occur. However, in identifying and measuring the individual substances which go to make up these classes, we are not nearly so fortunate. For example, the total amount of solid material in the atmosphere can be measured in any of several ways. But when it comes to measuring certain specific compounds, means of positive identification are still lacking. Even for the partial identification which is now possible, the procedures are tedious and expensive, and only a few laboratories in the country are equipped to undertake such a task.

Most of the measurement techniques for identifying trace quantities were originally developed for industrial hygiene use, where concentrations on the order of a few ppm were being measured. Now, in studying community air pollution problems, concentrations in the ppb range must be measured.

For a large number of substances, methods have been developed to obtain quantitative results from samples taken for periods of 24 hrs or longer. For a small number of the more simple gases such as sulfur dioxide, hydrogen sulfide, and carbon monoxide, for example, methods are available to show the concentration minute by minute. Among the substances which can be measured over longer time intervals, but which we would like to measure minute by minute, are aldehydes, olefins, polynuclear aromatic compounds, and some particular industrial effluents. Since concentration-time relationships are not well understood, studies for a number of different averaging times will have to be made until the relationship becomes clarified.

Another disadvantage in applying available methods is the matter of cost. Many of the instruments which are now available cost several thousand dollars apiece, which limits their application to situations where the information is urgently needed. Along with the development of new methods of atmospheric measurement, there is great need to make these methods commercially available at lower cost so that they can be more widely applied. Because of the recent history of the development and application of measuring devices, we have become accustomed to thinking in terms of elaborate devices, to the neglect of simple procedures such as impregnated test papers and other straightforward methods. Such techniques as film badges for workers handling radioactive materials, and the indicator crayon used by military forces to measure exposure to toxic gases could be extended to provide techniques for air pollution investigations. These techniques are all averaging techniques; similar methods responsive to peak concentrations are also needed. These might eventually be used in warning systems.

Most of the methods now in use have been adaptations of methods originally developed for other applications, and borrowed for use in air pollution research studies. Incentives need to be provided for the development of methods specific to the needs of air pollution. Special attention is drawn to gas chromatography as a separation technique, supported by infrared absorption and mass spectrography for identification purposes.

Even though our ability to identify and measure pollutants is not as far advanced as we believe it should be, it is much further along than our knowledge of the significance of these measurements as they affect the health and comfort of man.

(2) The trend in change of such

pollutants and their pattern of distribution?

The only pollutant for which we have a sufficiently long record of measurement to establish trend is settleable solids. For this pollutant, we know that there was a consistent downward trend for several decades, which has recently flattened out. Sulfur dioxide has been measured for over 20 yrs in a number of locations, but the results are not available to the public. Fluoride measurements have also been made for over 10 yr, but the results are likewise unavailable.

Other than these three pollutants, none have been systematically measured for over 10 yrs. The longest record for pollutants, other than fall-out, sulfur dioxide and fluorides, is that of the Los Angeles County Air Pollution Control District, where continuous measurement has been made since 1953 of oxidant. Systematic, continuous measurement of carbon monoxide and oxides of nitrogen was started in 1955, when the "alert" system was established.

Analyses of suspended particulate matter by the National Air Sampling Network of the Public Health Service were started on a small scale in 1953; however, for most communities associated with the Network, the starting date was January 1, 1957.

Direct measurements of soiling have been available for several years and are of considerable use in determining progress made in air pollution control.

Thus, it is apparent that long-term trends cannot be established by the data available to the public, for other than settleable solids and soiling index.

A recent survey of the location of continuous, automatic measuring devices for gaseous pollutants showed that 100 of these devices were located in California, 48 were scattered throughout the country in the hands of industrial organizations, and 10 were operated by public agencies outside of the State of California. Thus, it is obvious that data to indicate trends of gaseous pollutants are primarily confined to California. A true national picture of the distribution of suspended particulates has been obtained during the past 2 yrs by the National Air Sampling Network. This Network has the limitation of affording only 1 sampling site in each community, and, therefore, can at best only indicate the general level and type of contamination in the community.

The available measurements of settleable solids and soiling index are primarily from large eastern cities where coal is in widespread use as fuel. Outside of the coal-burning areas, there has not been the public demand for abatement which would lead to the continuous, systematic measurement of gritty and grimy materials in the atmosphere.

The available data show that definite correlations can be established between the type and amount of pollution and such factors as the size of a city, the type of fuel used, types of industry present, common methods of transportation, and other factors related to the patterns of our modern civilization.

(3) The specific effects of various topographic and meteorological conditions and of concentration or dispersal of sources on the concentrations of such pollutants?

Some knowledge has been available for many years concerning the diffusion phenomena which control the dispersion of pollutants from a point source. Originally developed because of military interest in the spread of a cloud of a toxic agent, this knowledge was later applied to studies of industrial emissions from a single stack. Early in this work, the effects of varying meteorological conditions became evident. One of the most exhaustive studies of pollutants from a point source was completed at Trail, British Columbia, where a complicated meteorological and topographic situation caused widespread pollution throughout an entire valley at certain times. A complete understanding of this situation was necessary before suitable control measures could be developed. The importance of the meteorological phenomenon known as inversion in affecting air pollution situations was first brought to the public's attention as a result of this investigation.

The application of point-source theory to community-wide problems involving multiple sources necessitates a complicated mathematical treatment which is only beginning to be explored. Meteorological measurements at ground level are frequently not sufficient for this purpose, and measurements above ground level are usually even less available. The relationships between meteorology and topography have been under study by meteorologists for many years, and are quite well understood for general flow patterns but not for dispersion of contaminants.

When a combination of unfavorable meteorological and topographic conditions cause air to become stagnant over a community, the possibility is greatly increased that reactions will occur in the atmosphere to produce substances radically different from the materials which were originally emitted. Many of these reactions are not completely understood.

One influence on the concentration of air pollutants may be the dispersal of sources. By applying general principles already known, sources of pollution can often be located relative to prevailing winds and other sources so that adverse effects on the surrounding community can be minimized. In other cases, lack of knowledge concerning a particularly complicated meteorological picture makes proper selection of source location difficult. In still other cases, where winds are extremely light and variable, little can be done from the standpoint of source location.

IB. What, if anything, should be done further on these matters, and by whom?

In identifying and measuring pollutants:

1. Effort needs to be expended in development of refined analytical techniques, to identify and measure pollutants which cannot be adequately measured at the present time in the ppb range.

2. More inexpensive methods are needed for continuous monitoring.

3. When monitoring pollutants, peak values as well as average concentrations should be determined until relationships are clarified.

In studying trends in change of pollution levels and their pattern of distribution:

1. Particulate sampling, as being done by the National Network, should be continued to study long-term trends.

2. Gas sampling should be initiated to study the distribution of gaseous pollutants throughout the nation and to establish long-term trends.

3. A National Network based on only 1 sampling site per community is inadequate to determine the distribution of pollutants within any but the smallest communities. This points up the need for the maintenance of monitoring programs conducted by local communities at locations sufficient to define the local problem. This more intensive local sampling should be conducted in such a manner that results can be compared with other communities and with the National Network results.

4. Much useful information could be obtained with little additional work if the results of previous unpublished sampling could be made available.

5. Monitoring programs should be reappraised at regular intervals to be sure that they remain dynamic in character and do not become self-perpetuating.

Concerning the effects of meteorology and topography:

1. Existing meteorological knowledge is not being used adequately for the solution of community air pollution problems. Communities should be shown how they can measure and use meteorological data inexpensively and conveniently.

2. Systems of meteorological measurement specific to the needs of air pollution investigations are needed. Most of the present meteorological measurements and observations were established to meet the needs of agriculture, aviation, etc., and do not provide the optimum service to air pollution investigations.

3. Better methods are needed to relate emission concentrations to atmospheric concentration, more particularly for area sources such as cities. Theoretical and experimental studies are urgently required, not only of diffusion at distances of 1 mile and beyond, but also of the rate of natural cleansing of contaminant gases and particulates from the atmosphere by the processes of washout, rainout, gravitational settling, and turbulent impaction.

4. A better delineation of the air pollution factors responsible for decrease of visibility is needed.

5. There is a need for better and more sensitive tracer techniques, with particular reference to the problems of tracing air movements within an urban area.

6. Recognizing that each community has a limit to the amount of pollution its atmosphere can accept, there is need for more knowledge of the interrelationships between meteorological and topographical factors for the establishment of these limits both for short and long time periods.

7. Atmospheric contaminants such as CO_2 which may be causing long period changes in our climate should be monitored on a national basis at appropriate stations.

In historical perspective, the first measurements of air pollution were supported by local governmental agencies. Industrial organizations responded to these initial efforts by initiating studies in their own laboratories and by supporting studies in educational and research institutions. With the advent of the Los Angeles problem, and the organization of air pollution control there on a county-wide basis, major research support for a considerable period of time became a county responsibility, later to be supported by state-sponsored efforts in California. In recognition of the fact that the problem of air pollution extended beyond the confines of California, federal support of research was sought and initiated. This federally-supported research has been conducted both directly in federal laboratories, by contract with research organizations, and by grants to individual researchers. A mechanism has also been developed in California through the establishment of a private foundation whereby funds from industrial sources are made available to support research in private research organizations. It is apparent both that there is no one best agency to support research, and no one best type of research organization to conduct this research. In our future planning, all methods of obtaining support must be tapped, both private and all levels of government. All available research facilities need to be used in the areas of their greatest competance, depending mainly on where competent individual researchers and suitable facilities are to be found. There is a definite need for recruitment and training of additional qualified persons to meet the challenge of modern air pollution problems.—Dr. Arie J. Haagen-Smit, *Chairman;* Dr. Herbert C. McKee, *Vice-Chairman;* Arthur C. Stern, PHS Resource.

Discussion Group "B" Sources of Air Pollution

Report and Recommendations

The speakers and members of Discussion Group B—"Sources of Air Pollution," met in accordance with the program for the National Conference on Air Pollution. As their Chairman, I have the honor to present the results of our discussions.

Our most important program of speakers delivered 9 papers, in the course of which various sources of air pollution were discussed; but let me say here that it was not possible, due to shortage of time, to attempt an all-inclusive coverage of possible sources.

As the printed program indicates, the items covered specifically were as follows: Domestic and Municipal Sources; Industrial Sources, such as: Petroleum Refining; Electric Power Generation; Metallurgical Processes; Chemical Processes; Automotive Vehicles.

The pollutants which were discussed represented in general the end products of combustion, the products of incomplete combustion, and the emissions of various kinds from process industries. Where quantities of pollutants were known or available, they were reported by the authors, and it is unnecessary to repeat this information here. However, it was discovered that information on the types as well as the quantities of pollutants was not known for all sources, and that many gaps in this information exist largely because of the lack of analytical and test procedures. The panel dealt principally with primary sources of pollution, but it was recognized that secondary pollutants may result from reactions in the atmosphere.

Information on the quantities and types of emissions is basic to the problem of control. This information establishes quantitative objectives for control and identifies substances which are known to affect health, damage property, or create nuisance.

In any locality, the significance of any single pollutant or group of pollutants will depend upon the amount, the topography, the meteorology, and the number of sources involved, as well as the density of the population in the vicinity. Each community is a specialized problem and the pollutants which may be of concern to 1 geographical area will not necessarily be a problem to another.

There is a need for determining the relationship between the emission rate of a specific pollutant and its effect on the environment. It is desirable to establish tolerance thresholds with respect to effects on health, growing plants and animals, and the creation of nuisances.

The history of technology suggests very strongly that patterns of emission from all sources will change in the future. An example of this is the substitution of nuclear energy for fossil fuels in the production of power. Similarly, technological development continually alters the types of emissions from chemical processing and manufacturing. The precise direction in which these changes will occur cannot be predicted, but the fact that they will occur is certain, emphasizing the need for continuing source appraisals.

The rapid development of urban areas makes the significance of future increases in pollutants particularly important since greater numbers of persons will be exposed to the effluents from these sources.

The opinion was expressed by many speakers that neither knowledge of types of pollutants at their sources nor present methods of analysis is adequate. It was pointed out that in some areas the methods of identifying pollutants are not specific enough. Furthermore, in certain cases where methods are known, they are either too expensive or too time-consuming, or both, and adequate methods for identifying minute quantities of pollutants are not readily available. We believe that there exists a need for knowledge and information on more specific, accurate, less time-consuming and less expensive methods for evaluating pollution sources.

In addition, there exists a need for a systematic compilation of available information on emissions from all sources, as well as a means for improved communication and dissemination of this information as it is developed.

We do not believe that the development of these improvements is the sole responsibility of any one agency, group, or individual, but that what is

needed is the co-ordination of the efforts of all groups who are interested in this problem. By this we mean that industry and manufacturers of equipment have a responsibility for establishing information on emissions from their processes and devices; that research organizations should be encouraged to contribute significantly in this field; and that communities should develop information relative to their pollutant sources.

There is a need to make generally available information on sources of pollution and to analyze these data in order to avoid unnecessary duplication and to serve as a guide to others investigating these and related problems. In this regard we believe that it is necessary and proper that the activities of the Public Health Service in the dissemination of this type of information be expanded and continued on a permanent basis.

It is the consensus of our group that no time should be lost in carrying out the suggestions made herein. The rapid growth of the population and of the national economy, and the attendant increase in the quantities of pollution from all sources indicates the need for immediate action.

In conclusion, members of Group B recommend that the Public Health Service implement the following program at the earliest possible date:

1. Intensive development of instrumentation for source analysis.
2. The provision for training of specialized personnel in source studies.
3. The encouragement of communities to assess continually the sources of pollution within their boundaries, with technical assistance from the Public Health Service if requested.
4. The systematic collection, analysis and dissemination of information on emissions from all sources in co-operation with local communities.—SYLVAN L. HANAUER, *Chairman;* DR. LESLIE A. CHAMBERS, *Vice-Chairman;* DR. AUGUST T. ROSSANO, PHS Resource.

Discussion Group "C" Health Effects of Air Pollution

Report and Recommendations

Concern about the actual and potential threat to health of atmospheric pollution has run through most of this conference. Several aspects of the health problem were noted by Dr. Burney in his opening remarks. Further references were made in various ways by Dr. Hilleboe, by Senator Kuchel, and by Dr. Leake in their remarks at the opening session. In his discussion of "What does air pollution do to humans?" Dr. Dixon summarized the current knowledge of the relation of atmospheric pollution to health.

From this general overview, Group "C" at yesterday's day-long session probed somewhat deeper into the problem. Our 200 participants devoted the 4-hr morning session to look at general and several specific aspects of the health effects of air pollution.

Mentioned in the first plenary session were several acute air pollution episodes. Our group analyzed in somewhat more detail these acute episodes and lessons to be learned from them. In medicine we often refer to subclinical disease. Along with the specific Donora and London episodes, consideration was given to other incidents that approached the level of clinical recognition.

In future years such events may well be recognized as acute episodes of lesser intensity when our observation acumen is sufficiently sharpened. Possible approaches to more scientifically and accurately studying these incidents were noted.

Also mentioned to you on Tuesday were possible chronic disease entities that might be attributed to long time and repeated exposure to low concentrations of air pollutants. Group "C" paid particular attention to this matter. Laborious epidemiologic studies were described which are essential to the elucidation of the role of polluted air in the causation of chronic diseases. Particular attention was paid to chronic bronchitis, asthma, emphysema, cardiac and circulatory diseases, and to cancer. There was some probing into the intricacies of the anatomical and physiological changes in the lungs and other organ systems resulting from exposure to atmospheric pollutants.

From this 4-hr session a number of generalizations seemed to come forth to those of us who participated. Much knowledge about the medical effects of polluted air is already available. Many potentially important and significant leads have been uncovered. The body of knowledge is increasing in many directions and at an accelerating rate. I, for one, was heartened by the evidence of progress. I'm sure that as each of you studies the reports we heard yesterday, you also will catch a glimpse of the horizons ahead through the gradually dissipating smog of the unknowns.

I cannot resist stating to you that over 95% of our participants stayed with us right up to the 1:00 P.M. adjournment of the morning session, so intense was the interest in the presentations.

In the afternoon, Group "C" divided into 6 discussion groups. The objective was for each group to consider specific questions that had been propounded by the Inquiries Committee. It was understood that the groups could go beyond the specific questions. At the end of the afternoon we reassembled and listened to the reports from each of the 6 groups.

In the time available, I cannot give you their complete reports but will attempt to summarize the conclusions and recommendations. There were several general recommendations that came in 1 form or another from several of the groups.

1. There seemed no question that the national Air Pollution Program should be continued and expanded.

2. In the continuance of the program it was emphasized that problems in air pollution will be with us indefinitely, so the specific enabling law should have no specified terminal date. As one group stated, there should be "permanent extension of Public Law 159."

3. It was recommended that placing a legal ceiling on appropriations was unrealistic; budgets should be considered annually by the Congress on a basis of current program needs and potential for effectively utilizing the funds.

4. It was concluded that since there are many unanswered health questions there should be acceleration of research on the health effects of air pollution. In such an accelerated program there should be participation by all agencies such as official health agencies, research organizations, universities and industries, including the automobile industry.

In this regard it was emphasized that there are existing research potential that, for lack of funds, are not being utilized.

5. It was recognized that intensification of control efforts should not and cannot await the definitive answers to many of the medical problems. However, there was agreement that it is imperative that such answers be found at the earliest possible time since they will serve to better guide the development design of control programs.

6. From 1 group came agreement that nuisance due to air pollution should be regarded as a public health problem. Among the reasons noted were the effects upon efficiency and upon emotional and physical comfort and well being. It was felt these effects need not necessarily be manifestations of specific disease entities.

7. One group specifically considered the responsibility of the voluntary health agency in the air pollution field. In summary, it was concluded that such agencies should participate in promoting air pollution control, in promoting and sponsoring health research, in supporting official agencies and in an educational capacity.

8. Another group paid particular attention to the responsibility of practicing physicians and recommended that: First, organized medicine, through national, state, and local medical societies, should collect and disseminate air pollution information to its membership; second, that the proceedings of this Conference be made available to physicians and public health authorities; third, that private physicians individually should be encouraged to use local facilities and services, such as those of local health departments or air pollution control authorities, to assist them in the management of clinical problems that may involve air pollution. Physicians should also serve as interpreters of the health aspects of the problem to their patients and to others in the community.

9. The question of "How would you estimate the impact of air pollution on your community health?" was considered by another group. Mentioned were eye irritation, irritation to the respiratory tract and upon emotional well-being, including anxiety about the possible hazard to health. They noted that because of incomplete information on the health effects of air pollution, community hysteria may develop which, among other things, may lead to unnecessarily restrictive laws.

10. Still another group considered the question of what should be the responsibility of government—federal, state, and local—in the determination of the health effects of air pollution. It was concluded that the current plan of co-operation among the 3 levels of government is effective and should be continued. In this instance I should like to quote the complete statement of the subgroup: "There was general consensus that grossly inadequate information on health effects of air pollution was available upon which to base sound, nondiscriminatory legislation to effectuate control."

In discussing the role of government, there was no intent to imply that the responsibility was government's alone, but that, indirectly, research groups, academic institutions, as well as other groups, do have a share in the responsibility of determining the health effects of air pollution.

There was developed a set of recom mendations designed to offset the lack of information on health effects and to delineate major responsibilities of the several levels of government:

1. In general, air pollution problems *common to the country as a whole* should be the responsibility of governmental agencies at all levels.

2. Problems more local in nature should be the primary responsibility of the pertinent area, but consultative advice and guidance should be available and sought from state and federal agencies.

3. Emphasis was given to an integrated team approach to the determination of the health effects of air pollution to provide efficient correlative data. Such a team approach would entail the collection of concurrent medical, epidemiologic, and aerometric data.

4. It was felt that local resources were not being utilized adequately and that additional useful medical statistics could be secured within the framework of well organized data collection programs involving the local health resources and facilities, such as health departments, registrars of vital statistics, practicing physicians, and hospitals.

5. Although more could be done with existing facilities, it was felt that an adequate program at the local level in most instances would require augmented financial support and intensive stimulation of interest.

6. As such significant health effects data become available, every effort should be made by the federal agencies to disseminate such information to the states and, similarly, by states to local agencies.

7. Since adequate methodology in determination of health effects and sufficient competent personnel were not yet available, it was felt that a crash program for definition of health effects was certainly not indicated at this time. In this regard, there should be promoted, instead, an orderly but aggressive program of research in this area.

In conclusion, may I say this report reflects only a sample of the many important problems considered by Group "C". I do want to express my deep appreciation for the contributions made by the many participants, the Public Health Service staff, and, particularly, Dr. Harry Heimann. It has been an honor to serve as chairman of such an illustrious group.—Dr. Malcolm H. Merrill, *Chairman;* Dr. James P. Dixon, *Vice-Chairman;* Dr. Harry Heimann, PHS Resource.

Discussion Group "D" Economic and Social Effects of Air Pollution

Recommendations

Education

We recommend a continuing and intensified education program in the following 4 areas:

1. The education of personnel so that the problems of the future can be met and solved.
2. The education of industry by the dissemination of existing information to industry's obligation for air pollution abatement.
3. The education and assistance for public officials in meeting local problems of air pollution.
4. The education of the general public in its obligations in controlling their own contribution to air pollution problems.

Research

The following areas need study:

1. The effect of air pollution upon organisms and materials.
2. Extent and cost of air pollution on our economy and society.
3. Extent and cost of air pollution control in our economy and society.
4. Research into administration and legal techniques of air pollution control.
5. Research on sociological implications of air pollution and air pollution abatement.
6. Research and development of new and less costly air pollution control techniques.
7. The encouragement of research in by-products and development investigations.

Action

The group recommended:

1. The continuation and expansion of Public Law 159.
2. The creation of a stronger liaison between government and the general public and the establishment of a liaison between government and industry. (With these efforts toward better liaison, we will have an understanding of the meaning of our living together in a co-operative effort.)
3. Governmental co-operation with local organizations in the development of programs and effective measures which will further effective and fair air pollution control.
4. Machinery be set up to promote periodic national meetings for the comparison and evaluation of air pollution control progress.—Dr. Christopher E. Barthel, Jr., *Chairman;* Arthur Crago, *Vice-Chairman;* Dr. C. Stafford Brandt, PHS Resource.

Discussion Group "E" Control Methods and Procedures for Air Pollution

Report and Recommendations

Summary

During the past decade, substantial progress has been made in basic knowledge and in the technology and practice of air pollution control. Industry and

government both have contributed to this progress. Industry is spending millions of dollars a year in research and hundreds of millions a year in control of air pollution. Government and nonprofit agencies are also spending large sums of money for similar purposes. These expenditures have resulted in substantial improvement.

Scientific, engineering, and trade associations have held numerous conferences on air pollution in recent years. Their publications have presented useful scientific and engineering developments. These publications have promoted wide application of the new knowledge, particularly in larger installations, but more effective use of the present knowledge can be made.

The means are presently available for adequate removal of many pollutants within cost limits which are economically feasible. Such means are not available for certain other pollutants, but in many of those cases removal is desirable but not essential. The economic justification depends on the conditions which exist in each instance. For many of those pollutants for which the need of control has been most urgent and widespread, economical methods for correction have been developed. In certain industrial applications the control cost results in a direct charge to the local industry which, in turn, passes this cost as an increase in consumer cost to the local community benefiting from the applications of control; in others, it results in a customer cost which is borne nationally. In the case of municipal and domestic sources, the direct cost of control is borne by the community.

It is recognized that a public awareness should be directed to the value of industry standards and principles applicable specifically to new installations having a significant air pollution potential for the purpose of minimizing the development of new air pollution problems in the future.

Recommendations

1. The Committee recommends that it is a joint responsibility of government and industry to sponsor and conduct research on air pollution control. It is recognized that industry welcomes government support of research as a means of identifying, defining, and developing approaches to solutions. The responsibility for the solution of specific problems associated with a specific industry or plant lies with that industry.

2. Further research and development should be implemented to expedite controlling emissions from high temperature combustion and metallurgical operations.

3. Further studies must be undertaken to develop economic means for the removal of low concentrations of gaseous pollutants such as oxides of sulfur and nitrogen from combustion gases for application in areas where these may be a problem.

4. We urge that the education and training of engineers in the field of air pollution control should be continued and if possible expanded.

5. Recognition should be accorded to the importance of developing economical survey techniques that can quantitatively define the relative importance of the application of control equipment in a community.

6. Properly designed and engineered control equipment should be incorporated in the initial plant specifications. Codes for guidance in this practice should be developed by voluntary industry groups and engineering societies. Support for this endeavor should be encouraged.

7. In regard to automobile exhaust emissions, the following recommendations are made:

   a. Work on the development of analytical techniques and instrumentation and studies of exhaust gas composition should be continued by both industrial and governmental agencies.
   b. Those industries presently engaged in developing exhaust system control devices should continue their work at a vigorous rate.
   c. The automobile industry should continue its study of the maintenance aspects of the automobile exhaust-air pollution problem.

8. Research agencies should continue their program on the health aspects of all air pollutants in order to expedite the development and application of control methods.

9. The study of atmospheric reactions should be continued so that as control methods become available those urban areas affected with an air pollution problem can determine whether or not the application of such control methods will be effective in their particular problem.—DR. LESLIE SILVERMAN, *Chairman;* WESLEY C. L. HEMEON, *Vice-Chairman;* ANDREW H. ROSE, JR., PHS Resource.

Discussion Group "F" Administrative Aspects of Air Pollution

Report and Recommendations

1. *Q:* What are the respective responsibilities of the individual, business and industrial activities, and public agencies in the prevention and control of air pollution?

A: The control of air pollution requires the co-operation of the whole community. While an industrial source may contribute more than an individual, it should be recognized that the total contribution to the air pollution load by individuals may equal or exceed that of industry. The individual has responsibility to prevent or reduce air pollution resulting from open fires, trash incineration, home heating plants, and improper functioning of his automobile within the technological limits which exist at the time.

As an integral and vital component of the community, business and industry have a responsibility in the prevention and control of air pollution as a good neighbor and for the general welfare of the community. In this regard, it is incumbent upon them to recognize that air is a limited natural resource. The use of the air is common to all, and neither public use nor custom grant special consideration to any components of the community.

Local public agencies have responsibility for dealing with the air pollution problem through several approaches. First, the community must take the initiative in providing services for the collection and disposal of refuse in a manner which will not pollute the air. Second, the public agencies should conduct their operations in an exemplary manner to avoid pollution of the air. Finally, that local or regional public agency, capable of dealing with the air pollution problems in the area, should be given the responsibility for the conduct of a control program. This intends that recognition be given to those factors common to such an area because of topography, meteorology, sources of pollutants, and effects.

The appropriate state agencies should assume responsibility for leadership, technical assistance, and guidance to the local control agencies. In this manner, the state can function effectively by assisting local agencies in appraising their air pollution problems and providing necessary technical assistance. The state agency should also maintain a continuing program of study and appraisal of air pollution levels throughout the state. The state should encourage local control legislation and local control operation, where feasible, but the state should assume the responsibility for control in all those areas where the organization of local or regional programs is not feasible, or where a local control program is needed and has not been established.

The most effective manner in which to assess relative responsibilities in a community would be by means of preliminary study and appraisal of the air pollution problems. This should be followed by a determination of responsibilities in a co-operative manner, recognizing the equities in-

volved.

The role and responsibility of the federal government is clearly expressed in Public Law 159 of the 84th Congress. This Act provides for the conduct by the Public Health Service of a program of research, technical assistance, and training. This law was enacted in 1955 and provided for an initial period of 5 years of federal activity in this field with the intent of reappraising the problems and needs at the end of that time. Although much needed research results have been achieved, it is not possible to accomplish the objectives of the Act within the 5-year period. For example, the effects of air pollution on health and the control of automotive exhaust gases are but 2 of the many vital problems on which further work needs to be done. In the public interest there is continuing need for research which can best be conducted by the federal government. The nation-wide importance of air pollution problems indicates the real need for amending Public Law 159 to extend the authorization for the program.

The Congress in enacting Public Law 159 also included a provision limiting the annual appropriation to a maximum of $5 million. Air pollution research includes many complex aspects involving study over an extended period of time, particularly those concerned with the chronic health effects. This fact, together with the possibility of an engineering or medical research "breakthrough" which might make desirable an expansion of activities for further development and exploitation, suggests that no appropriation limitation should be included in the extension of the Act. The annual budget review and appropriation procedure provide adequate financial control. The air pollution problems of our country are so vast in scope and, if unchecked, will without doubt increase in severity due to the rapid increases in industrialization and urbanization which are taking place; therefore, we feel it is undesirable that a ceiling be placed on the funds authorized by the congress for work by the federal government in this field.

II. *Q:* In general, in the conduct of air pollution control programs: (*a*) Should air pollution control be organized on a local basis? Regional? State? Other?

A: Public Law 159 specifically declares it to be the policy of congress to preserve and protect the primary responsibilities and rights of the states and local governments in controlling air pollution. This policy declaration is clearly in harmony with the federal constitution under which the police powers, with certain exceptions, are reserved to the respective states. Thus, the control of air pollution, as an exercise of the police power, is a responsibility primarily of the states and, to the extent delegated by them, to their political subdivisions.

In many cases, air pollution can be dealt with by a single local political subdivision. Air pollution, however, frequently does not respect political jurisdiction and consequently many communities are unable to deal effectively with this problem on an individual basis. Experience, thus far, clearly indicates the desirability of meeting the air pollution problem on a problem-area basis. This would involve, as the case may be, purely local or regional efforts, the latter by interlocal or interstate co-operation. As one practical approach, the Council of State Governments has suggested state enactment authorizing co-operative activities between local subdivisions on a joint basis. The act would permit the exercise of power already possessed by a political subdivision in conjunction with one or more communities for a common end. It should be noted that the suggested act is drafted for use between or among communities whether or not they are located within a single stage.

There are some situations which are primarily regional and dependent upon a number of common factors, such as weather, topography, population concentration, and industrial development, among others. A number of state legislatures have recognized this need and have enacted appropriate enabling legislation. In the control of air pollution, it is clear that the functions of the states lie in two general categories: (1) those concerned with the legal delegation of appropriate powers to their political subdivisions or groupings of them, and (2) those concerned with the direct activities of the state government itself. For the first, state initiative and action is a necessary antecedent to effective local or regional activities. In addition, there is need to encourage co-operation and co-ordination between states in dealing with interstate air pollution problems. The federal government in the exercise of its jurisdiction over commerce on navigable waters should delegate authority for control of air pollution to the states.

(b) *Q:* What relative emphasis should be placed on education, voluntary action, regulation, legal enforcement?

A: The active co-operation of the various components of the community is most desirable and essential for a successful air pollution program. There is also the necessity of achieving a proper balance among the elements of a community air pollution program, appropriately tailored, which would include among others, education, co-operation, regulations, and legal enforcement. Education of all concerned plays an important role in securing understanding and co-operation. It provides the means of describing the problem, needs of the community and what can be done.

The rules and regulations establish the objectives. The promulgation of such rules and regulations performs the significant function of guidance and provides a uniform approach, where applicable, to the air pollution problem. Obviously, for the recalcitrant few, there is need to resort to legal remedies. The legislation must be reasonable and just, based upon a sound technical foundation.

(*c*) *Q:* What is the role of the zoning in air pollution control?

A: At the present time, satisfactory acceptable variations in standards of air pollution control relating to zoning and planning have not been evolved, It is recommended that planning and zoning experts, working together with air pollution officials, devote further study and research to this problem.

(*d*) *Q:* How should air pollution control be paid for?

A: This question involves two aspects: first, that involving the cost of operating the control agency; and second, the cost of providing and operating processes or equipment for actually preventing or controlling air pollution.

All segments of the community are concerned with the control of air pollution and many of them are affected by the financial equities involved. The official control actions, undertaken in the over-all public interest, should be supported therefore by public funds. This may be tempered by an appropriate system of equitable fees covering the cost of special services rendered by the official agency to individuals or business and industrial organizations.

On the other hand, every individual or organization must be expected to defray the cost of necessary steps in preventing or controlling air pollution which would otherwise result from activities carried on or controlled by him.—Dr. Louis C. McCabe, *Chairman;* Harold W. Kennedy, *Vice-Chairman;* Samuel M. Rogers, PHS Resource.

EVALUATION of *Absorption* SAMPLING *Devices*[*]

LOUIS R. ROBERTS and **HERBERT C. MCKEE,** Southwest Research Institute, San Antonio, Texas

Introduction

The selection of suitable sampling methods frequently presents serious difficulties in studying air pollution problems. Various methods have been used, including absorption in a liquid solution, adsorption on activated carbon or other medium, condensing or freezing the pollutants at low temperature, or reaction with a reagent on a solid carrier such as a filter paper.

Of those methods, absorption of pollutants in a liquid solution has probably been most widely used. Some of the reasons for this popularity include the great number of analytical methods available to analyze the resulting solutions, the reproducible results that can be obtained with reasonable care, and the comparative ease of obtaining data.

Various devices have been used for adsorption of pollutants from the atmosphere. One very common method is to use an ordinary gas washing bottle, which consists of a cylinder to contain the solution, plus a fritted glass diffuser to break up the air stream and promote more efficient absorption. Other devices which are commercially available include:

1. The Midget Bubbler,[1] similar in operation to the gas washing bottle but smaller in size to permit using as little as 10 ml of solution.
2. The Greenburg-Smith Impinger,[2] similar to the gas washing bottle but with the substitution of a high-speed orifice for the fritted glass diffuser, arranged so that the air impinges on a flat surface as it emerges from the orifice, breaking up into small bubbles to promote absorption.
3. The Midget Impinger,[2] similar in principle to the Greenburg-Smith Impinger but reduced in size to take as little as 10 ml of solution.

The latter two types were originally intended for collecting dust particles in a liquid medium, but are also useful for sampling gaseous pollutants.

An investigation was undertaken to attempt to design absorption samplers which would possess better operating characteristics, including high efficiency, use of small volumes of solution to increase analytical sensitivity, and the use of high flow rates to permit obtaining data with shorter sampling periods. The time of sampling was considered important both from the standpoint of approaching instantaneous values rather than long-time average values, and also from the standpoint of economy in obtaining more data/manhour expended in field work. Since the labor and operating costs of a two-man mobile laboratory may exceed $200/day, the matter of economy is an important consideration.

As a first step in the development of new types of sampling equipment, the operating characteristics of samplers now available were determined. Operating conditions were deliberately extended well beyond the intended range in order to establish limits for the present samplers.

This paper presents data obtained in evaluating samplers now available. A subsequent paper will cover the results being obtained in the development and design of new types of samplers.

Experimental Procedure

Fig. 1 illustrates the experimental method used in evaluating samplers. Standard atmospheres were prepared by diluting cylinder gases in a two-stage dilution board. Similar dilution boards have been used by others and are quite convenient for a variety of applications. In this study, "Predictability" flowmeters[3] were used to measure the gas and air flows to establish the proper dilution ratio. The calibration data supplied with the flowmeters was checked with a wet test meter and was found to be within the limits of experimental error in reading the flowmeter and wet test meter.

Air from the laboratory compressed air system was passed through a pressure regulator set for approximately 9 psig, an activated carbon container, a paper filter, and then a Precision "Drift-Proof" pressure regulator[4] set for approximately 3 psig before going to the dilution board. The exact setting of the pressure regulators was immaterial, but the precise control obtained with the second regulator was a great help in maintaining constant air flow rates.

After mixing in the first stage, most of the resulting stream was discarded through a vent. A small portion passed to the second stage for additional dilution with purified air. By choosing the proper flowmeters for both stages, concentrations of a few pphm could be obtained in the second stage.

Throughout the system, minimum lengths of tygon tubing were used to join flowmeters, tubing, and valves. Apart from these joints, only glass and stainless steel contacted the gas mixtures.

The devices being tested were placed downstream from the dilution board, using three absorbers in series. The dilution board was used to establish approximately the desired concentration, but the efficiency of absorption was determined by the ratio of pollutant retained in the first absorber to the total retained in all 3 absorbers. By using a fourth absorber in series, it was determined that substantially complete absorption was obtained in 3 absorbers in all cases. As predicted by theory, it was also found that each absorber retained approximately the same percentage of the pollutant which entered; that is, if the first sampler retained 90% of the original pollutant, then the second sampler retained 90% of the amount remaining, etc.

Most of the experimental work was performed using 1 of 3 gases as pollutants: ammonia, sulfur dioxide, and chlorine.

Ammonia was collected by absorption in distilled water, followed by colorimetric analysis using Nessler's reagent.[5]

Sulfur dioxide was collected in diso-

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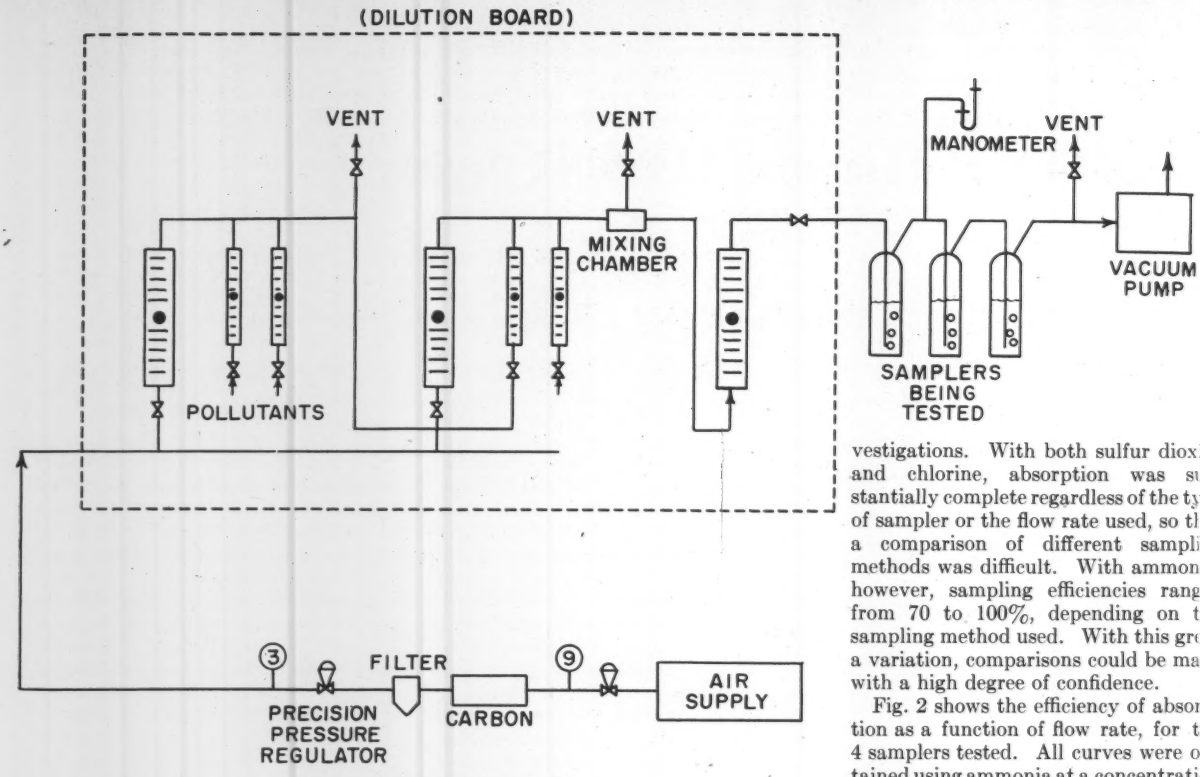

Fig. 1. Experimental equipment

dium tetrachloromercurate for analysis by the method of West and Gaeke.[6]

Chlorine was collected in 0.1 N sodium hydroxide, and analyzed colorimetrically with o-tolidine reagent.[7]

A Bausch & Lomb Spectronic 20 spectrophotometer was used for all analyses.

Experimental Results

Of the three pollutants investigated, ammonia was chosen for detailed investigations. With both sulfur dioxide and chlorine, absorption was substantially complete regardless of the type of sampler or the flow rate used, so that a comparison of different sampling methods was difficult. With ammonia, however, sampling efficiencies ranged from 70 to 100%, depending on the sampling method used. With this great a variation, comparisons could be made with a high degree of confidence.

Fig. 2 shows the efficiency of absorption as a function of flow rate, for the 4 samplers tested. All curves were obtained using ammonia at a concentration of 1 ppm by volume. Note especially the small variation in efficiency of the Greenburg-Smith Impinger at all flow rates tested up to 1.0 cfm, which was the highest obtainable with the equipment setup used. The gas washing bottle, on the other hand, showed higher

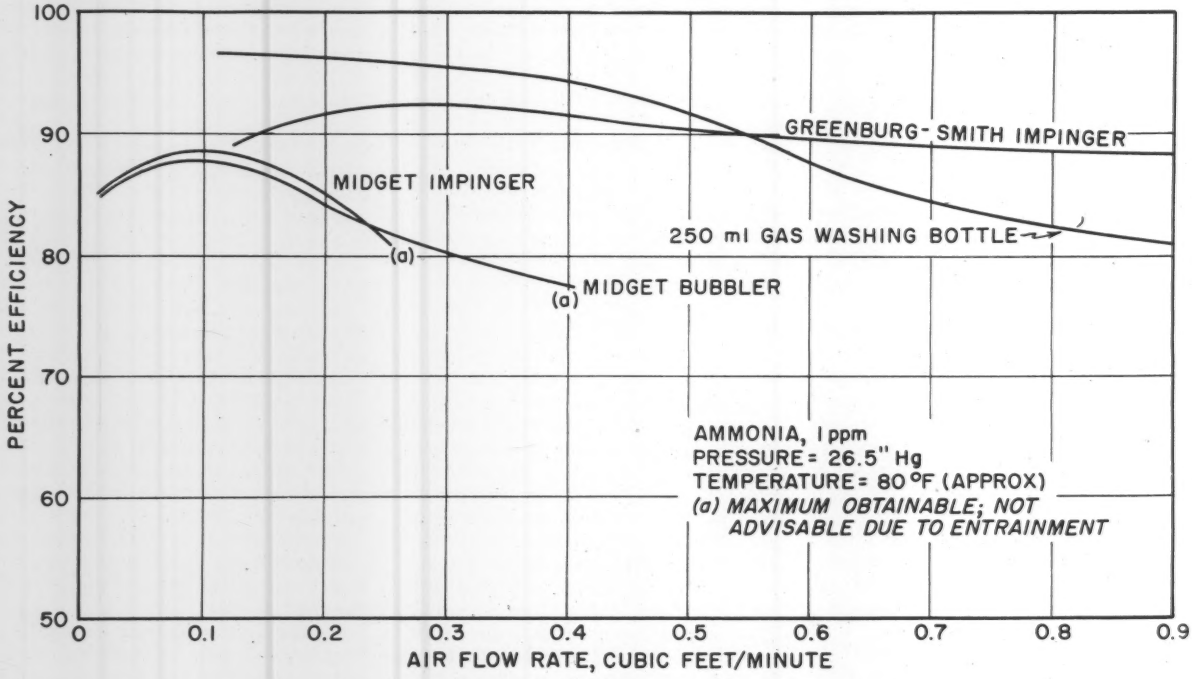

Fig. 2. Performance curves—Commercially available absorbers

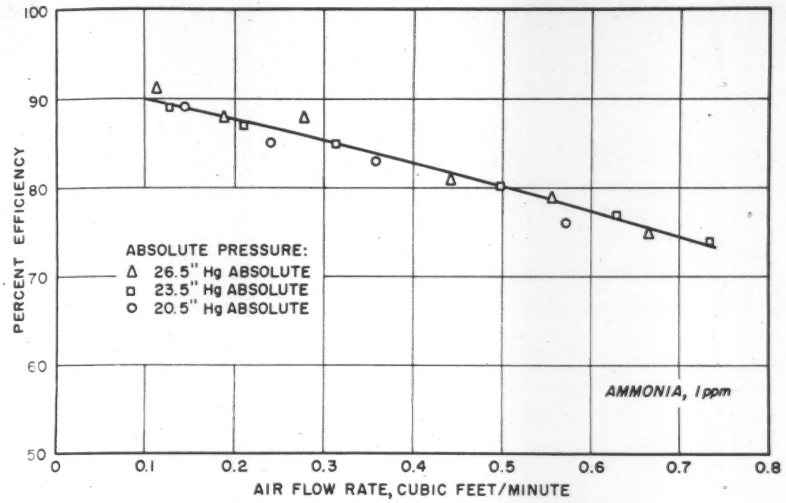

Fig. 3. Performance curves—Volumes corrected for pressure changes.

efficiency at low flow rates, but lower efficiency at flow rates in excess of 0.6 cfm.

The point marked (a) on the curves for the Midget Impinger and Midget Bubbler represent the highest flow rate obtainable; above this figure, the liquid absorbing solution is literally blown out of the sampler into the vacuum line in a short time. Even at flow rates less than these limits, operation is not satisfactory due to the low efficiency and due to the loss of some of the absorbing solution by entrainment. At the design flow rate of 0.1 cfm, however, operation of both is satisfactory.

Discussion

As is well known, the rate of absorption of a gas by a liquid is governed by the conditions prevailing at the interface between the two phases. In many cases the absorption reaches a state of equilibrium wherein the rate of gas molecules entering the liquid phase is equal to the rate of gas molecules leaving the liquid phase, with the net result being no further absorption after this condition of equilibrium is reached. Any chemical or physical phenomenon which changes the concentration of either the gas or liquid phase will shift the equilibrium.

This principle probably explains the high efficiency obtained with sulfur dioxide or chlorine. In either case, an irreversible chemical reaction occurred, thus removing the gas from the liquid solution as fast as it was absorbed. However, the solution of ammonia in water to form ammonium hydroxide is reversible, so that any phenomenon which affects conditions at the interface between liquid and gaseous phases is certain to affect the equilibrium and hence the absorption efficiency.

It has been shown that absolute pressure variations do not affect the rate of diffusion of gas molecules through a gas film.[8] It is also known that gas film resistance is the rate controlling step in the absorption of highly soluble gases.[9] This situation would be expected in air pollution sampling since, for most gases, the solution would be far from saturated at the conclusion of a normal sampling run. In order to test this expected relationship, tests were made at three pressures, 26.5, 23.5, and 20.5 in. of mercury absolute. Volumes were calculated to the pressure existing in the sampler in each case. The data are shown in Fig. 3. Within the limits of experimental error, it appeared that pressure changes did not affect absorption efficiency. Therefore, it is believed that the gas film resistance exerts a major influence on absorption, and that liquid film resistance is negligible in controlling the rate of absorption and hence absorption efficiency. This information is being used in designing new types of sampling equipment.

The effect of temperature on absorption has not been completely established. Solubility of gases in liquids is increased by a decrease in temperature, which would favor more efficient absorption; however, temperature effects on gas viscosity are such that a part of this advantage is cancelled so that the net effect of temperature changes is not large. Fig. 4 shows the result of cooling the absorbing solution to near freezing for two different absorbers. While the efficiency may be improved slightly, the improvement is not significant except at high flow rates. Certainly, from a practical standpoint, it is not worth the trouble and effort required to cool the sampling device in an ice bath during sampling operations in the field.

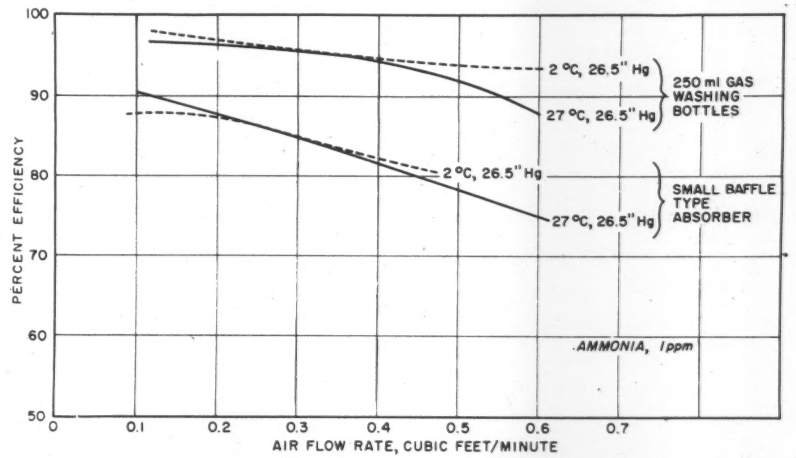

Fig. 4. Performance curves—Effect of temperature on efficiency.

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Control of Air POLLUTION *at* COMINCO OPERATIONS*

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Introduction

The basic ingredients of life are sunlight, air, water, and soil.

By processes of evolution living things adapt themselves to moderate changes in environment. Mankind has even learned to modify and utilize the materials that form this earth to his advantage, but in so doing leaves a collection of waste products behind. These often make the material unfit for use by his fellows.

Modern industry needs both air and water to help separate waste products from the useful product being manufactured.

Pollution of both air and water becomes obnoxious as the density of population increases. Control of this pollution, whether from industries or individual sources, is necessary if our civilization is to survive.

The alternative to a well-controlled future where people can live together in harmony and health is a life restricted by waste products.

Cominco is playing a part in this development of harmonious surroundings.

Historical

A great metallurgical industry was born at the turn of the century at Trail, B. C. Its growth and development during 50 years has been accompanied by the inevitable problems of pollution, (Fig. 1).

The mines of The Consolidated Mining and Smelting Company of Canada Limited in the southeastern part of B. C. turned out an increasing tonnage of lead-zinc ore. These ores were separated into lead concentrate and zinc concentrate—the two metals being associated largely with sulfur.

Before smelting and refining, the sulfur must be separated from the metal by roasting and is released as SO_2 gas. During the first 25 yrs of operation this sulfur increased from 900 tons per month to nearly 7000 tons per month, all of which escaped to atmosphere in these early days. In the second quarter century the sulfur treated rose from 7000 tons per month to 14,000 tons per month, yet the amount escaping into atmosphere at the present day is less than it was in 1900 A.D.

During the 1920's, farmers south of the U. S. border—10 miles away from Trail—began to object to this foreign invasion which they claimed was impairing their crops. Legal action was taken and an International Tribunal was set up to assess the damage and prevent its continuance.

The investigation produced some fine work by such men as Morris Katz, which work laid the foundation for the modern science of air pollution control.

Commencing in 1928, Cominco built sulfuric acid plants to utilize the waste sulfur. This acid went into the manufacture of fertilizer products such as ammonium phosphate and ammonium sulphate (Fig. 2).

The fertilizer industry brought its own problems of pollution with phosphates, nitrates, sulphates, and fluorides and other wastes requiring proper disposal.

The whole development program, which stems from the waste sulfur, was costly, but in the long view became a profitable enterprise.

Production of sulfuric acid runs to nearly 1300 tons per day at the present time at Trail and another 200 at Kimberley (Fig. 3), all of which goes to fertilizer manufacture.

This program of continuing expansion has necessitated a close watch on waste disposal problems, which are our concern here.

Control Methods

Control methods were developed by Cominco as the necessity arose. Metal losses were controlled by electrostatic treaters in the very early days. At the time of the International Tribunal, SO_2 was the only gaseous contaminant controlled. Since then all forms of pollution, whether solids, liquids, or gases, are subject to control. A special department of trained men is employed for this purpose.

As waste products all originate in the chemical and metallurgical processes, close liaison is necessary with the operating personnel to ensure the best possible operation and maintenance of equipment. Variation in the actual process is often recommended to decrease losses to atmosphere.

Measurement of all substances detrimental to the supply of pure air is carried out continuously. As there are more than 100 stacks and vents at the Trail metallurgical and chemical fertilizer plants this represents a large sampling schedule. A complete record of stack emissions is vital to any control program.

The dispersion of stack effluents is greatly affected by the weather. For this reason Cominco finds it desirable to operate a weather station (Fig. 4). By measuring the movement of the air and observing other characteristics such as temperature, humidity and pressure, and extending these movements into the future it is possible to estimate where our air pollution will drift and at what concentration.

The next procedure is to monitor or measure the concentrations of potentially dangerous pollutants at various distances from the source. A continuous record is kept of concentrations at certain locations many miles from our plants.

With these several procedures carried out, we can assess any possible nuisance created by the smoke, whether it be to vegetation, animals, or humans.

The successive steps required for controlling air pollution may be described as follows:

1. Where does it originate and how?
2. How much is there and how strong is it?
3. Where does it go and how fast?
4. How strong is it when it gets there?
5. What harm would it do?

* Paper presented at C.I.C. Chemical Engineering Division Conference at Vancouver, June 3–5, 1957.

Fig. 1. Trail smelter.

The answer to these questions gives us the information necessary to design equipment or revise processes in such manner as to control air pollution.

Application of Methods of Control

A well-trained smoke observer must work in close co-operation with the operating and maintenance departments and have an understanding of the chemical and metallurgical reactions carried out in the plants. This means careful choice of men followed by suitable training to carry out control practices.

Standard methods of stack gas testing are used by Cominco. Bag filters are employed to catch dusts and chemical tests measure gases, depending on their nature. Wherever possible, continuous recorders are used for SO_2. At Trail there are six continuous SO_2 recorders working on large stacks. Whenever the SO_2 concentration exceeds a set amount a red light indicates to the smoke observer and the operator that adjustments are necessary.

Less important pollutants are measured periodically on a scheduled basis—some once per day—others less frequently.

Meteorological instruments include barograph, temperature and dew point recorder (Foxboro Dew Cell), wind velocity recorders (Hastings, Bendix Friez, and Anemometer), turbulence integrators (Bridled Cup Anemometer). Much valuable information is obtained from the Department of Transport and the U. S. Weather Bureau by weather and forecasts.

Monitoring the atmosphere in the neighborhood is carried out by instruments, with telemeter connections, showing a duplicate chart in the central control office. Under this heading the Thomas SO_2 recorder is used (Fig. 5). We have 4 of these instruments at Trail and 1 at Kimberley.

This instrument measures the electrical conductivity of a standard sulfuric acid solution containing hydrogen peroxide. Any absorption of SO_2 increases the conductivity which is recorded on strip charts as parts per million SO_2.

By installing a second slide wire to the shaft of the recorder a signal can be transmitted over regular telephone systems and duplicate recorders in the central Smoke Control office show a continuous recording of SO_2 concentration up and down river from Trail.

Another useful tool in the measurement of SO_2 is the PbO_2 test developed in Great Britain (Fig. 6). A canvas is secured around a plastic cylinder fixed to a stand. On the canvas is smeared a paste of PbO_2 which is exposed to the atmosphere for one month and then analyzed for sulfur. A figure is obtained of grains of SO_2 absorbed per sq ft per month. This is a cheap test to install and gives a good geographical distribution of air pollution for that month. It is particulary useful in corrosion studies.

Other field tests carried out are filters and settling pans for particulates, and impinger tests for some soluble pollutants.

A useful method of measuring solids which settle out of the atmosphere is by taking snow samples. During periods of unbroken frost we have covered large areas in this manner.

Particle size determination plays an important role in these surveys. The larger particles, over 10μ, settle or are washed out of the atmosphere. The finer particles down to 0.1μ do not settle and move with the air in the same manner as gases.

Hence we use SO_2 concentration as a general indication of the distribution of all forms of pollution in the area.

An important tool of the smoke observer in the field is the natural vegetation growing in the area based on the fact that different species of vegetation react differently to impurities in the air.

Smoke control men make a careful observation of trees, shrubs, weeds, and garden plants during the spring and summer and are able to distinguish between SO_2, fluorides, etc., by the effects they produce. Generally, these confirm results of chemical tests and extend the area of our observation. Close contact is maintained with farmers and horticulturalists.

This particular field of observation is complicated by onslaught of plant diseases, soil deficiencies, insects, and parasites of all kinds. Sometimes it is necessary to employ experts in these fields of science to convince farmers that their crops are suffering from things other than smoke.

An important function of the smoke observer is the assessment of nuisance which could be perpetrated by air pollution. These nuisances include corrosion of metals, restriction of plant growth, and production of fog. This fog forms around a nucleus of dust and fume particles and if sufficiently concentrated could be unhealthy.

The formation of "smog" is an interesting phenomenon of our times. It is a combination of man-made nuclei, dusts, smoke, fumes, etc., with natural condensed moisture.

At times of high barometric pressure and low wind velocity it is possible for air pollution to increase to unhealthy amounts. This has happened several times in recent years at such places as Pittsburgh, Los Angeles, and London, England. Even Vancouver has been plagued with it. At Trail we are aware of the possibility and have a program ready should such an event occur.

Cominco has installed a large corrosion testing station near Trail where various metals, paints plastics, etc., can

Fig. 2. Fertilizer plants near Trail.

Fig. 3. Fertilizer plant near Kimberley, B. C.

be exposed for long periods of time under measured atmospheric conditions. Comparisons are made with other stations located across Canada in the larger centers.

Standards

No scheme of measurement and monitoring can be successful without a standard by which to gauge the results. For this reason standards have been set for all stack emissions at Trail.

The standards are derived by studying the results of several years' operations and are considered to represent normal operation.

Whenever new corrective equipment is installed to reduce the loss, then the standard is adjusted to suit.

Trail standards compare favorably with other published standards.

At the present time much work is being done to set suitable national standards in U.S.A. and Canada but the best basis is not yet agreed upon, as each locality has its own conditions and standardization is difficult.

The very basis for standards is controversial and must state whether it is necessary for human well being or plant life.

The ultimate standard perhaps will be one which will avoid nuisance to

Fig. 4. Thomas SO_2 recorder.

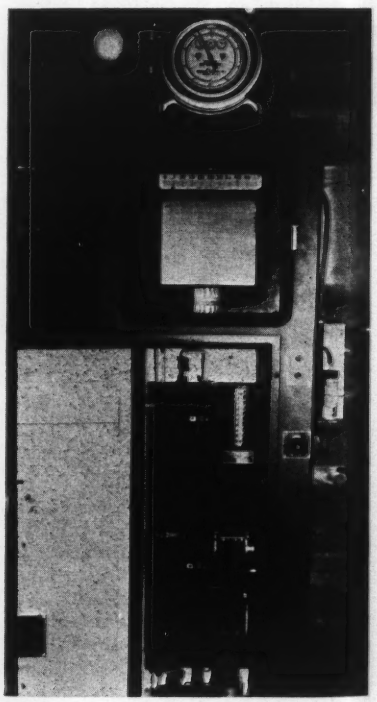

Fig. 5. Lead peroxide stand for SO_2 measurement.

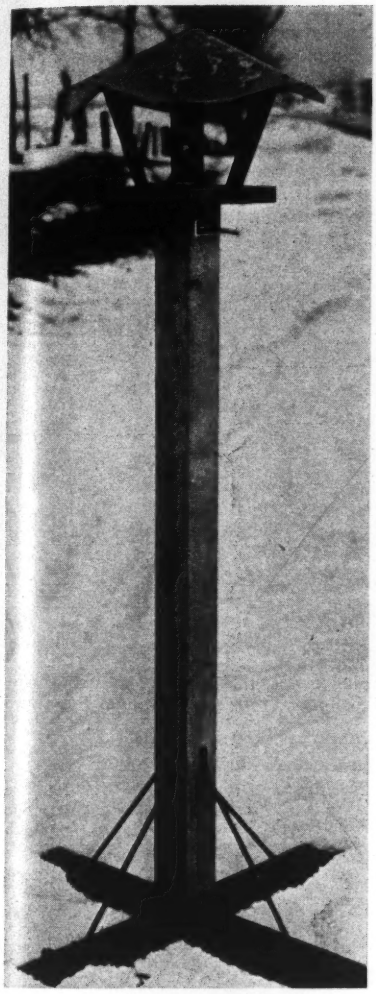

Fig. 6. Central control office and weather station.

neighbors whether it be a man, his dog, or his garden.

A universal law appears to be almost an impossibility unless it is so general as to be useless.

Smoke Abatement Equipment

From the very early days, Cottrell electrostatic treaters were used to curtail metallurgical losses. Blast furnace outlet gases, sintering plant gases, zinc roaster gases, and zinc melting room gases were all treated in this way for the recovery of values. The total volume of gases amounted to over one million cubic feet per minute. Recoveries averaged 95% of the metal treated. The use of cyclones for coarser dusts was confined to smaller operations.

In 1930 a new process to recover the metallic ingredients of blast furnace slag by fuming was introduced and a baghouse installed to filter the oxides from the gas stream. The efficiency of bag filtering and the increased metal recovery has promoted the further use of baghouses on blast furnace gases, the old treaters being scrapped.

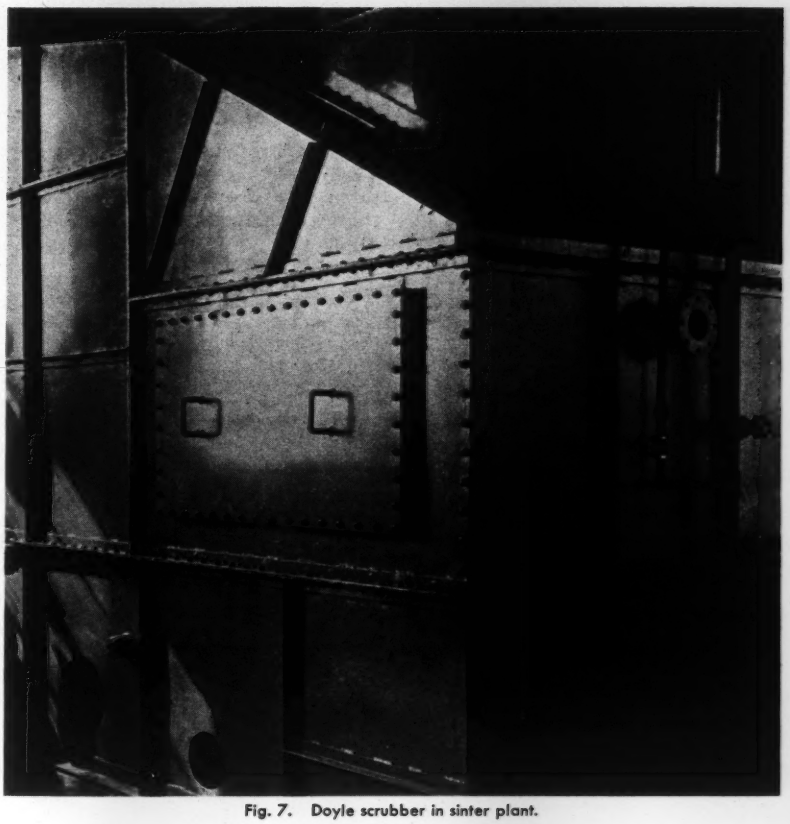

Fig. 7. Doyle scrubber in sinter plant.

Many smaller baghouses have been installed on furnace gases throughout the lead-zinc operations.

A more recent development in the recovery of solid particles, particularly those of small dimension, such as metallic oxides of particle size 2–5 μ is the wet scrubber. At Trail, a scrubber was developed known as the Doyle scrubber (Fig. 7). This piece of equipment comprises a jet formed by a conical obstruction in a round pipe. The annular jet permits the dust particles to be injected violently into a water bath by means of a high pressure drop induced draft fan.

The ventilation gases in our new sintering plant are all scrubbed by Doyle scrubbers and a high recovery maintained. The fact that recovered solids are in the form of a mud instead of dry dust has required some modification of existing processes.

Gaseous losses to atmosphere have demanded a totally different approach to abatement.

Gases must be absorbed to be caught. SO_2 was our main problem and many absorption media were tried.

At concentrations above 4.5% SO_2 the standard sulfuric acid process is practicable but below that some form of concentration becomes necessary.

At Trail the weaker SO_2 bearing gases are all scrubbed with a solution of ammonium bisulphite. Sufficient aqua ammonia is added to maintain a predetermined pH. The final solution is of such a strength that on acidification a saturated solution of ammonium sulphate is formed. This solution is evaporated and the solid ammonium sulphate is marketed as crystals.

The acidification process releases SO_2 at 100% concentration and this is currently added to sulfuric acid plant feed to give a 10% gas.

One sulfuric acid plant treats 100% SO_2 and pure oxygen to produce a large tonnage of acid with less equipment than the conventional plants.

While the technology involved in these processes may seem relatively simple, the large quantities being handled entail a very large capital investment. At the present time we have 6 sulfuric acid plants producing a total of around 1300 tons of H_2SO_4 per day at Trail and an additional 200 tons at Kimberley.

Most of this is used in the manufacture of ammonium phosphate.

The air pollution problems associated with manufacturing ammonium phosphates, ammonium nitrate and ammonium sulfate call for technical treatment quite different from the other processes mentioned.

Our Doyle scrubber has been used very successfully to control losses of

fluorides, dusts, and ammonium salts to atmosphere.

Each problem of air pollution has to be studied on its own conditions. The physical state of the pollutant, its size, density, chemical characteristics, and also its effect on its surroundings must be examined before any choice of abatement equipment can be made.

The cost of such equipment can be very high where large volumes are concerned and is often a major obstacle in any program of industrial air pollution abatement.

The Future for Cominco

Cominco realizes that the time has passed when any industry can continue to operate if its air pollution constitutes a nuisance. Industry must conduct its operations without jeopardizing the health, property, and well-being of its employees and of its neighbors.

Cominco, like most Canadian industry today, aims to be in business for a long time to come and so tries to be a good citizen of its community and of its country. It can only attain this objective, if, through voluntary self control, it refrains from harmful pollution.

ANNUAL MEETING EXHIBITORS

The exhibits shown at each Annual Meeting constitute a vital portion of the program. Following is a partial list of the exhibitors who are participating. We suggest that you visit these exhibits and take advantage of this opportunity to see the most modern equipment used in air pollution abatement.

Airkem, Inc.
New York, New York

American Air Filter Company
Louisville 8, Kentuckey

American Incinerator Corporation
Detroit, Michigan

Beckman Instruments, Inc.
Fullerton, California

Buell Engineering Co., Inc.
New York, New York

Business News Publishing Co.
Detroit 26, Michigan

Caloric Appliance, Inc.
Jenkintown, Pennsylvania

Catalytic Combustion Corporation
Detroit, Michigan

Chemical Construction Corporation
New York, New York

The Ducon Co., Inc.,
Mineola, New York

Encyclopedia Britannica, Inc.
Los Angeles 57, California

Gelman Instrument Co.
Chelsea, Michigan

Joseph Goder Incinerators
Chicago, Illinois

Koppers Co., Inc.
Baltimore, Maryland

Mine Safety Appliance Co.
Pittsburgh, Pennsylvania

Morse Boulger Destructor Co.
New York, New York

Oxy-Catalyst, Inc.
Wayne, Pennsylvania

The Perkin-Elmer Corporation
Norwalk, Connecticut

Research-Cottrell, Inc.
Bound Brook, New Jersey

Research Appliance Co.
Allison Park, Pennsylvania

Thompson Ramo Wooldridge, Inc.
Los Angeles, California

Tracerlab Inc.
Waltham, Massachusetts

Western Precipitation Corporation
New York, New York

A VERSATILE, *High Flowrate* TAPE SAMPLER

JOHN S. NADER, Chief of Instrumentation, Community Air Pollution Program,
Robert A. Taft Sanitary Engineering Center, U. S. Public Health Service, Cincinnati, Ohio

Tape samplers have been designed and used to collect atmospheric particulate matter on which different kinds of analyses would be performed. The types of tape samplers predominantly in use however have relatively low air flowrates and permit too limited a variety of analyses of the collected samples. This limitation is due to both the small mass of particulate matter comprising the sample spot on the tape and the nature of the filter medium employed. The particulate tape sampler described here uses comparatively high air flowrates per unit area of filter medium and concentrates a relatively large mass of particulates in the sample spot, using a filter medium which lends itself to a number of nondestructive analyses and to a final destructive analysis of each sample.

Design Criteria and Data

The objective in this development has been to obtain multiple analyses from the same filter sample, namely, nondestructive tests such as mass loading, soiling, radioactivity and x-ray diffraction, and destructive tests such as microchemical analysis, particle count, and size distribution.

Paper and fiber glass filters permit the highest air flowrates but are not compatible with the analytical techniques intended to be used because of their mass and penetrability. The membrane type filter, however, overcomes these objections satisfactorily.[3]

Measurements were made on several grades of membrane filters* to determine their performance characteristics (air flowrate vs pressure drop). Data were obtained also on the conventional paper filter tape and fiber glass filter for comparative evaluation. Results (Fig. 1) showed that the type SM membrane filter was superior in flowrate performance to the other types of membrane filters and not far different from the fiber glass filter. The microweb WS type, however, was selected because its mechanical strength made it available and usable in tape form, and its air flowrate characteristic was satisfactory.

In a preliminary approach to the development of a membrane tape sampler, an AISI Sampler was modified to use a membrane filter tape. The relatively low air flowrate (approximately 1 l/min/sq cm) did not provide the particulate concentration required for mass loading analysis in sampling periods of 1- or 2-hr duration. In this sampler, the diaphragm pump is not capable of the pressure drops required by membrane tape for higher flowrates.

To aid in the selection of an appropriate pump for the sampler, the performance of various sized pumps† was compared with the flowrate characteristic of the WS membrane filter (Fig. 2). These vacuum pumps are of the oil-less, carbon vane, rotary type, capable of continuous duty with a minimum of maintenance. Model #0240 appears to have sufficient capacity up to the cutoff point of approximately 12 in. of mercury. Although model #0440 is slightly larger (about 2 lbs), it was chosen because it allows a wider range of flowrates and, by reason of its slight oversize, adds a safety factor to the design.

Prototype Sampler Construction and Operation

A prototype sampler (Figs. 3 and 4) was developed using the Model #0440 pump and the type WS tape filter. The flow system (Fig. 5) was designed to bleed excess air through a bypass control valve at a flowrate equivalent to the difference between the pump capacity (max of 89 l/min at 2 in. Hg) and the filter flowrate. The resulting range of total air flowrate through the tape is from 5 l/min at 2 in. Hg to 32 l/min at 15 in. Hg. The pressure drop across the

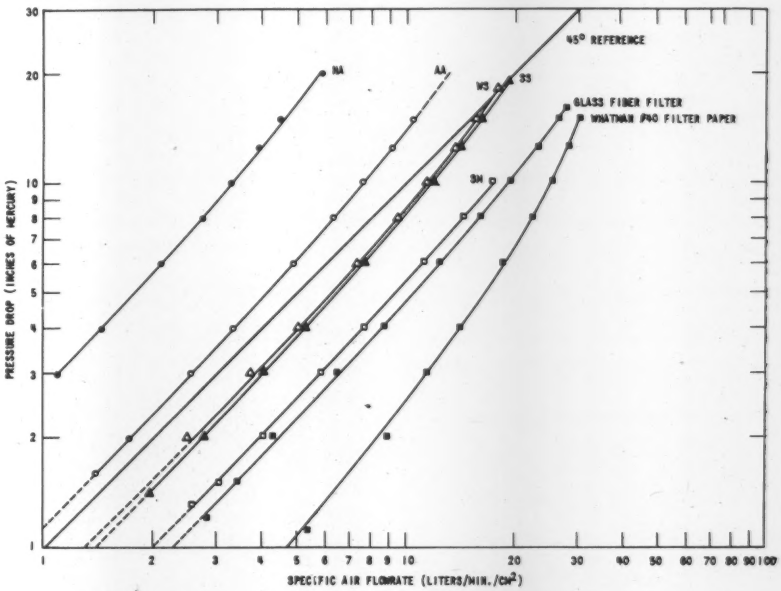

Fig. 1. Air flow characteristics of filter media for tape sampler (Millipore types HA, AA, WS, SS, and SM).

* Millipore Corporation.
† Gast Manufacturing Corporation.

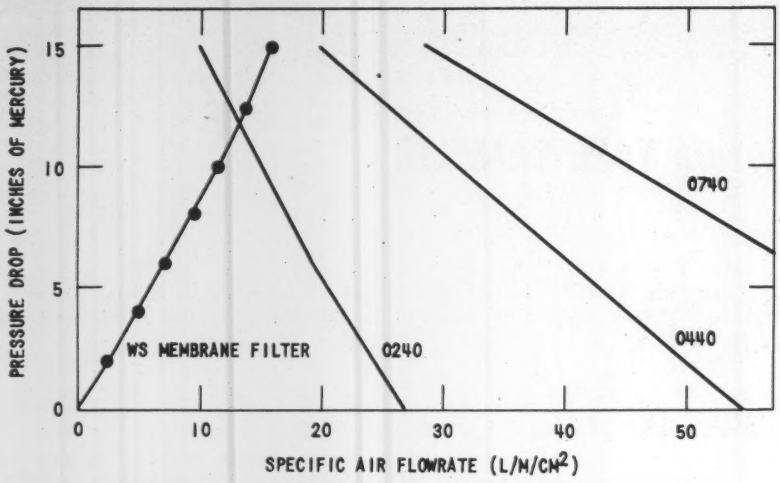

Fig. 2. Rotary oil-less vacuum pumps flow rate characteristics (MFG's data).

filter is measured by the vacuum gauge and, on the basis of the performance curve (Fig. 1), is an indicator of the filter flowrate. A plug of fiber glass is used as an air cleaner to prevent particulates in the bypass air from contaminating the control valve. The muffler attached to the exhaust reduces the noise generated by the pump.

A special spiral-loading cartridge (Figs. 5 and 6) was developed for storing the filter tape after sampling. The spiraling of the tape and the clearance between layers permit the sample spots to remain intact and undisturbed. The spiral contour is defined by a series of pins with free-rolling glass tubes which reduces the frictional forces encountered by the moving tape. Before sampling, the cartridge is preloaded with a lead-in tape which is used to draw in the sampled tape. The spiral length is approximately 50 in. which, with several inches for external lead-in, provides a storage capacity of 52 in. Since the cartridge is detachable and the tape self-contained, reloading is quickly achieved by the use of accessory cartridges.

The tape supply spool is spring loaded to maintain a uniform and nominal tension on the tape and to prevent unrolling. It has a capacity up to 100 ft of tape, allowing for approximately 23 cartridge loadings.

Sampling spots on the filter tape are evenly spaced by means of an indexing switch, activated by uniformly spaced indexing holes punched in the tape (Fig. 7). These holes are spaced 22 mm apart, allowing 6 mm between sampled areas (16-mm diam circles). The cartridge capacity of 52 in. corresponds to 60 sampled spots. The cartridge capacity as a function of time depends upon the sampling period selected, i.e., 2-hr sampling cycles will give a cartridge capacity of 120 hrs or 5 days.

The filter tape is moved automatically to a new sampling spot at the end of a preset sampling period. An automatic timer controls the duration of the sampling period over a time range of 0 to 30 hrs in marked $^1/_2$ hr intervals. The timer also deactivates the pump during the interval (approximately 30 sec) that the tape is being indexed to a new sampling spot.

Representative sample spots (Fig. 7) outline the area of the opening in the plastic sampling head. In this opening the membrane filter, supported by a recessed fine-mesh screen, seals itself at the edge of the opening as a result of the operating pressure drop. Fringe discolorations are obvious indications of leakage. Distinctly outlined sample circles are evidence of a good seal. To substantiate proper sealing, flowrate measurements were made with the self-seal technique and with a positive seal. The difference was found to be within 2% of the readings and within the error of reproducibility in making the measurements.

Compactness was maintained in the construction of the sampler, the dimensions (10 in. h x 17 in. w x 15 in. d) being limited basically by the size of the pump and motor. The front panel, enclosed by plastic, contains the controls and an air inlet tube for sampling. Motor and pump heat is readily dissipated through the open grill of the metal covering. The carrying handle, which must sustain the total weight (54 lbs) of the sampler, is attached to supports bolted to the base of the instrument.

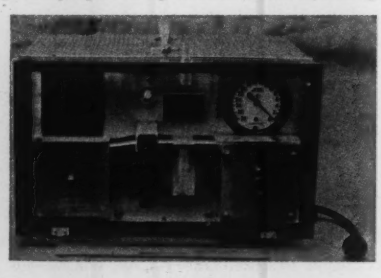

Fig. 3.

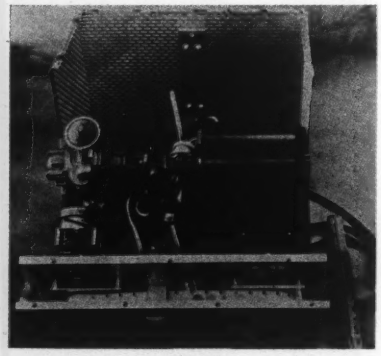

Fig. 4.

Accessory Units

The tape sampler is intended to be the basic unit of an instrument system utilizing several accessory unit analyzers. The indexing technique and tape storage device permit transfer of the sampled tape to the accessory units. Present intentions are to design these unit analyzers for automatic digital printout and punched card or tape data-handling.

The first accessory unit analyzer is currently under development. It measures the beta radioactivity and the mass loading of the particulate on the tape. A beta-gauge technique is used to make the mass loading measurements in terms of micrograms of particulates/m³ of air. Soiling measurements will be performed by an analyzer utilizing standard reflectance and/or transmittance techniques.[1] Accessory units for particle size, microchemical, and x-ray diffraction analyses may be developed in the future adapting current measurement techniques.[2–5]

Summary

The development and operation of a versatile, high flowrate tape sampler for atmospheric particulate matter have been described. Total air flowrate through a filter area of 2 sq cm is adjustable over a range from 5 to 32 l/min. The filter medium is the type WS microweb membrane in tape form. A number of non-destructive analyses and 1 or 2

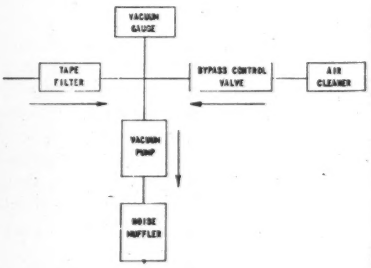

Fig. 5. Sampler flow diagram.

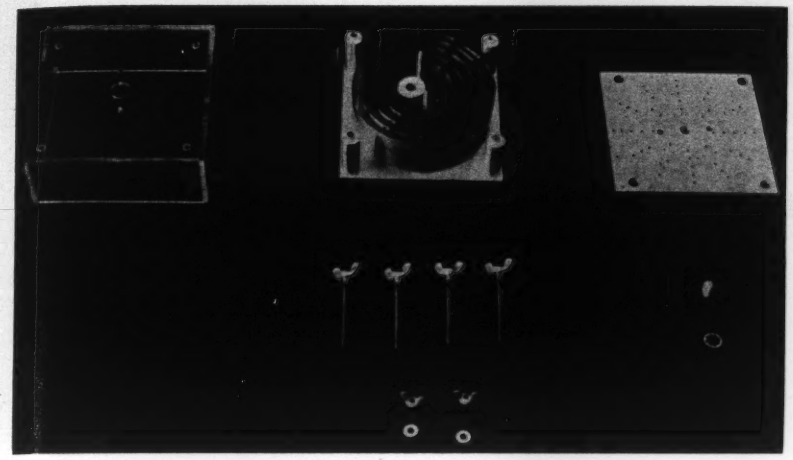

Fig. 6.

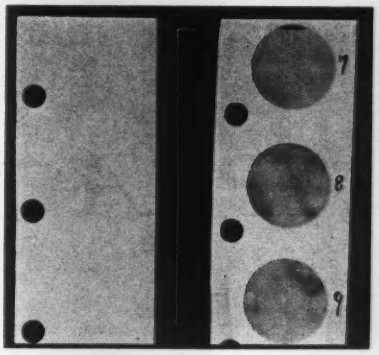

Fig. 7.

destructive type tests may be performed on particulate matter as it exists on the membrane tape. The instrument has been designed as the basic unit of a system of several accessory units by which various types of analyses can be made automatically on the sampled tape.

Acknowledgment

The author expresses his appreciation to his staff members, Morgan Massey, JA San.E., and Charles Norris, electronic technician, for their assistance in the construction and testing of the instrument, and to Dr. A. T. Rossano, Jr., who suggested the need for such an instrument.

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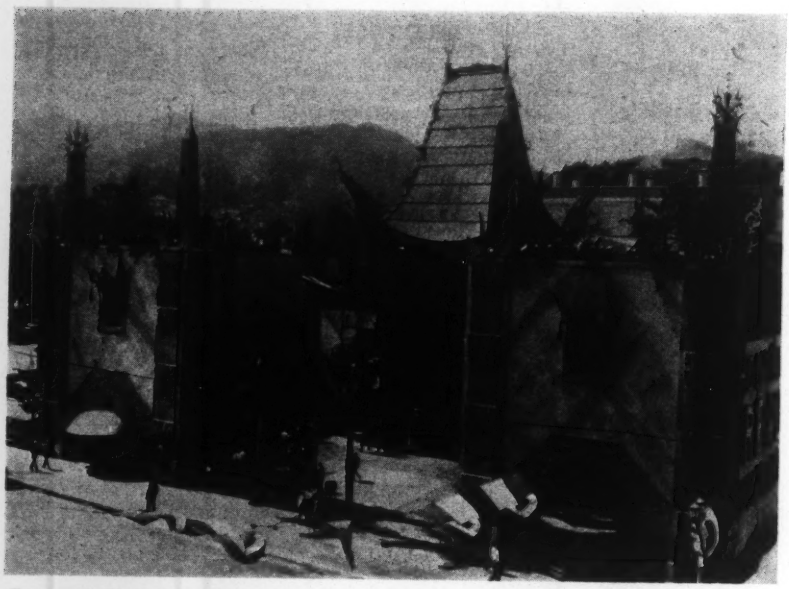


Grauman's Chinese Theater

June 21–26, 1959

Statler Hotel

Air POLLUTION *Resulting from* INCINERATION—*Its* REDUCTION *and* CONTROL*

LEO P. FLOOD, M.E., P.E., Member A.S.M.E., Chief Engineer,
Department of Air Pollution Control, City of New York

Definition: Air pollution is the presence in the air of substances put there by acts of man in concentrations sufficient to interfere with comfort, safety and health of man or with the full use and enjoyment of his property.

During the past 50 years, the people of the United States as well as those in many other parts of the world have increased their standard of living tremendously—this has had many side effects, such as an increase in leisure time, better education for more people, better communication from radio, television, and means of rapid transportation, better medical care, and a greater voice in government. The public, therefore, is informed on the evil effects of air pollution, has the time to consider its right to cleaner air, so conducive to comfort, health and conservation of property, and means to voice its demands for this essential natural resource.

Need for Air Pollution Control

Hazard to Health and Safety. Many of you are aware of the disaster in London in 1952, when during a five-day period of heavy air pollution the number of deaths in London was 4000 over normal. During the subsequent 12 weeks 8000 more died. In our own country a few years before that, a similar incident occurred in Donora, Pa. Other incidents have since occurred and are liable to occur in almost any place if the conditions are right. It is true that most of the casualties were persons either very old or very young and most likely in a state of poor health. But the fact that these people, less rugged than most of us, succumbed during periods of heavy air pollution, indicates that even the healthiest suffers some damage. Physicians are more and more coming to the view that air pollution is one of the causes of lung cancer—this conclusion being reached largely because the incidence of this disease is much greater in highly populated areas. Only recently, as reported in the issue of *U. S. News and World Report* of October 17, Dr. Mark D. Hollis, Asst. Surgeon General of the United States, in this connection said:

> "In air pollution we are not particularly concerned about general disease, even though some pollutants are highly irritating and may cause tissues to be more susceptible to common infection but, we are concerned with the possibility of uncontrolled air pollution causing or aggravating chronic ailments."

Again, a recent health column in the *New York Daily News*, by Dr. Theodore R. Van Dellen, was headlined as follows: "Air Pollution a Headache—Law Enforcement Is Cure." It is clear, therefore, that the public demand for strict air pollution control will become louder and more urgent as time goes on.

An aspect which should not be overlooked is that of decreased visibility, both on the road and in the air, caused by air pollution. Indeed, the Airplane Pilots' Association has on a number of occasions sent representatives to meetings of air pollution control officials to bring this matter to their attention. Which of us has not at one time driven behind a poorly maintained diesel truck whose smoke, not only offended our eyes and nose, but also obscured our view.

Economic Loss. Soiling and abrasive dusts, and corrosive acids borne in the air are the principal culprits causing great economic loss to all of us. The cost to New York City alone has been conservatively estimated at $100 million per year, $12 for every inhabitant. How obvious is the soiling of buildings when the original surfaces are revealed during cleaning operations. A few years ago the City Hall, in downtown New York was entirely refaced at a cost of several millions of dollars—the deterioration of this architectural gem was almost entirely due to air pollution. Corrosion of metals is another common consequence of the acids in the air. More frequent painting both for the protection of structures from corrosion and that necessitated by soiling from our airborne dust costs millions per year. The housewife's laundry and cleaning bills are higher in polluted areas than where the air is reasonably clean. What about the additional labor by the housewife in cleaning dust and dirt from air pollution? Our lighting bills also are higher when smoke from air pollution casts its dismal pall.

Discomfort and Inconvenience. In the metropolitan area the economic loss by damage to buildings and other structures may be borne by relatively few of the population, since only a small proportion are property owners. Physicians are reluctant to attribute physical ailments and sickness to air pollution, since they are principally concerned with relieving the condition they find, rather than determining the causes. All of us, however, are conscious of the discomfort and inconvenience caused by air pollution. Dust on floors, window sills, and furniture is a result of settled grit or dust due almost entirely, in city areas, to air pollution. The irritation to eyes and nose from noxious gases and dust in the air is another result. Many of us have become so inured to these conditions that we feel they are inevitable, and get respite only by a visit to the seashore or country. Indeed, the obscuration of the sun by suspended air pollution not only affects our comfort and health, but even our dispositions.

Incineration

Definition: Incineration is a reduction of refuse by burning without nuisance to a non-putrescible residue.

The higher standard of living has increased the amount of waste generated by the public and the tremendous concentration of populations has decreased

* Presented at the PROCESS INDUSTRIES SESSIONS OF THE A.S.M.E. ANNUAL MEETING New York, N.Y., November 30–December 5, 1958.

the land available for disposing of it by land-fill—the most economical method. To reduce the bulk of the refuse, it must be burned so the land available for dumps may be conserved for incombustible waste and incinerator residue. Everyone realizes the necessity for incinerators, but they are unanimous in their opinion that these necessary facilities should be located as remotely as possible from their homes.

Is Such Unpopularity Deserved?

This is too often true because many municipal incinerators are designed with only a single object in mind, and that is—reduce the waste. The secondary objective of doing this without nuisance and to a nonputrescible residue is almost entirely neglected. The operator also is under pressure to burn at or over the designed capacity, and it is usually our air which suffers from this overloading. Sometimes the city fathers who provide the money for incinerators are not informed on the damage caused by air pollution and, either eliminate entirely the necessary controls or, provide only for token controls which are usually ineffective.

Most communities build an incinerator only once in a life time—they must, therefore, depend upon a proprietary design, that is, one which an enterprising engineer or manufacturer promotes. The field is competitive and the art obscure so that the city officials, in most cases, know only as much about the merits of the various designs as the sales engineers will tell them. Design parameters are guarded trade secrets and there is little exchange of information among engineers versed in the art and very little knowledge made available for exchange among city engineers. If the bulk of the refuse generated is reduced, the primary objective is achieved and the installation is considered a success.

Pollution from Incineration

Smoke. Smoke is finally divided particles of unburned carbon in colloidal suspension in the chimney gases. It is offensive to the eye, an indication of poor combustion, and a serious source of air pollution. Fortunately, its elimination is relatively simple by improved design and operation.

Most jurisdictions have established rules which specify the density of emitted smoke which is illegal and a nuisance per se. The density of the smoke is determined optically by comparison with a smoke shade chart, usually the Ringlemann or a modification of it. This is a chart showing four shades of gray—No. 1 Ringlemann being equivalent to 20% smoke density, No. 2—40%, No. 3—60%, and No. 4—80%. In New York the emission of smoke denser than No. 3 for more than two continuous minutes in any one hour is a violation. Most incinerators do not violate this code unless there is some rubber or other high carbon material in the refuse.

Gases. The gases emitted include the products of complete combustion, viz; carbon dioxide, sulphur dioxide, oxides of nitrogen, and water vapor. These are unavoidable in the combustion of refuse and, if discharged at sufficient height for rapid dispersal, are tolerable. The nuisance-producing gases are the products of incomplete combustion and may consist of some or all of the following: carbon monoxide, ammonia, benzene, aldehydes, phenols, organic acids, and esters.

In a properly designed and operated incinerator no noxious gases, except sulphur dioxide and oxides of nitrogen, need be produced. However, during the starting period and in poorly operated or designed incinerators noxious gases are emitted and tests have indicated that these may be as much as 60 lbs/ton of refuse burned. These can not be detected by ordinary observation but only by test or their effects on persons, animals, plants, and property. In order to take legal action against such emissions, a nuisance must be proved. This is not a simple thing to do. Such emissions are particularly needless, since they may be so easily avoided in large central incinerators.

Dust. The particulate matter or solids carried by the combustion gases consist of particles of ash and unburned fuel. These particles vary in size from about 120 μ, or 0.005 in. in diameter to below 5 μ or 0.0002 in. About $^1/_3$ of the total dust emitted from incinerators, is smaller than 10 μ. Small particles are very slow to settle and those below 1 μ may remain suspended indefinitely. Since particles 10 μ in size take about 10 min to settle 10 ft in still air, positive means other than gravitational must be taken to remove them from the gas stream. Particles over 50 μ make up about 45% of the total dust. These are relatively easy to remove.

Dust emitted is the biggest source of air pollution and cause of nuisance in central incinerator operations. Limitations may be stated in allowable weight of dust emitted per 1000 lb of flue gases or grains of dust per cu ft of gas reduced to standard conditions of temperature and pressure. Each of these carries the condition that the values be connected to 50% excess air. Limitations set by many jurisdictions are 0.85 lb of dust/1000 lb of flue gas or 0.4 grain per standard cu ft, both corrected to 50% excess air. These two standards are approximately equal. There is another criterion used by many laboratories and plant operators. This is the weight of dust emitted per ton of refuse burned. Since the refuse may contain as much as 30% glass or metal or may be entirely free from these, this method is only a rough check on the performance of the control equipment.

Quantities of dust emitted in modern well-designed plants may be as low as 0.4 lb/1000 lb of flue gases, whereas if only elementary control equipment is used, the dust emitted may be as much as 2.0 or 3.0 lb 1000 lb of gas both corrected to 50% excess air. The values on the basis of pounds per ton of refuse may vary from 3.0 in a good plant to 20 pounds in a bad one.

There are many who misunderstand the meaning of the phrase "corrected to 50% excess air" so an explanation is in order. Obviously if the stack gases are diluted by air which is unnecessary for combustion, other things being equal, the weight of dust emitted per unit volume of gas will be much less than if only the minimum necessary air is used for combustion. Since the sampling is on a volumetric basis, if results are to be comparable, they must be reduced to a common standard. Therefore, a gas analysis is always made in connection with a dust sampling from a combustion process. If the composition of the fuel being burned is known, the percentage of carbon dioxide in the stack gases will indicate the amount of excess air used. Many people seem to think that because the dust emission is stated on a basis of 50% excess air, that this is a condition under which the incinerator must be operated. This is not the case. It can be operated with any degree of excess air or any deficiency of air as long as the weight of the dust is reduced to the standard basis.

Area Affected by Pollution

Not only are the immediate neighbors of an incinerator affected by the quality and quantity of stack effluent, but since the gases and fine dusts may be carried many miles from the point of discharge or remain suspended indefinitely, the general public also is vitally concerned.

Means of Control

It is axiomatic in air pollution control that it is better to prevent air pollution than to allow it to be generated and then remove it before it is discharged into the atmosphere. Also, removal from the gas stream is better than discharging it, even though it may be quickly dispersed. Discharge at a proper height and under conditions which would lend to rapid dispersal, is necessary for those gases which cannot be reduced further, and for the very fine dust which cannot be removed. All three of these methods are, or should be, used in the control of air pollution from central incinerators.

Control of Smoke and Noxious Gases. Incineration is a combustion process, and the means for good combustion

are the same for refuse as for other fuels. True, refuse is a nonuniform fuel sometimes containing a great deal of moisture and foreign material but nevertheless for any single area the mixture remains fairly regular. The fuel part of this refuse is predominantly cellulose and is composed of a mixture of garbage, paper, vegetation, wood, grease, etc. It has a volatile content of up to 70% on a moisture and ash free basis. The charge to the incinerator consists, not only of fuel, but also of noncombustibles, principally metal and glass, which may be as much as 25% of the refuse as charged. Moisture content varies depending upon weather conditions and the season of the year, and in extreme cases it may be 60% by weight. Heating value is about 6000 BTU/lb on a dry basis.

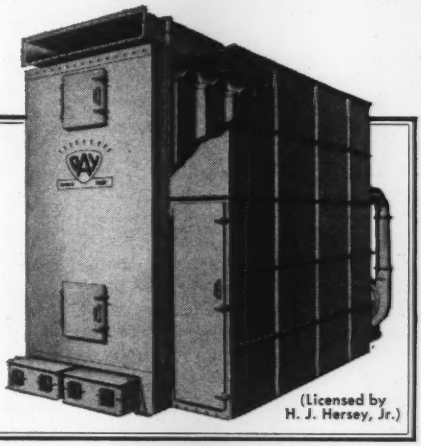
Because of the high volatile matter, a large part of the combustion air should be introduced over the fire. Air introduced through the firebed stirs up dust and therefore should be held at a minimum. Correct use of the overfire air will also increase the turbulency in the furnace so necessary for complete combustion of the gases. Temperature sufficient to kindle and maintain combustion is also an essential requirement. Finally, the furnace and burning rates must be so proportioned that the combustibles are retained in the furnace long enough to be completely burned. Excess air should be kept at a minimum but in no case should be more than 100% over that theoretically required.

Air should not be used as a coolant in order to prevent excessive furnace temperatures. Temperatures should be controlled by controlling the burning rate or by abstracting the heat through water cooled walls. Using too much air in the furnace has the effect of increasing the velocity through it, and therefore decreasing the residence time of combustibles. It has a chilling effect and may decrease the temperature so much that unburned combustibles are leaving the furnace. Finally, the increase in the volume of gases and the consequent increase in velocity serves as a carrier for dust which must be either removed at a later stage in the process or discharged into the atmosphere. Air should be used in a thrifty manner, that is, the air introduced for combustion purposes should be introduced at the proper location with sufficient velocity to contribute a maximum of turbulency in the furnace.

It is fallacious to hold the furnace temperature so low, in an endeavor to conserve refractory, as to sacrifice the proper conditions for completing the combustion process. Complete burning is the prime purpose of the incinerator. In my opinion heat shock, caused by alternate heating and cooling of the refractory, is a more serious cause of

DAY

DUST CONTROL NEWS



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99.99+% filtering efficiency

The real "pay off" on DAY "AC" filters is their ability to clean dust laden air with near perfect efficiency! Even "tough" materials such as carbon black or atomic energy materials are filtered with optimum effectiveness.

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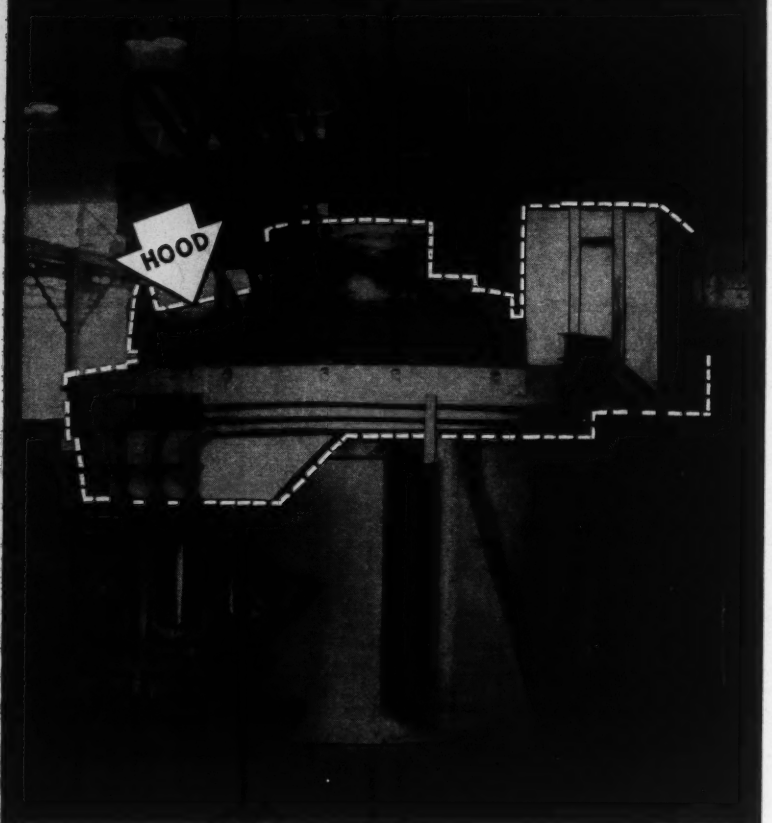

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Pangborn CONTROLS DUST

rapid deterioration than maintaining a uniform temperature high enough for proper combustion.

Controlling these combustion conditions in the furnace will completely burn any unburned carbon in suspension and thereby eliminate smoke. Maintaining the temperature in the range above 1500 to 1600°F will burn the gaseous pollutants and reduce them to sulphur dioxide, carbon dioxide and water. Keeping the volume of air at the minimum for combustion and introducing it at the proper place will decrease the amount of dust stirred up and carried over to be removed later or discharged.

Dust Control. If the furnace is properly designed and operated, the smoke and noxious gases are consumed within it, and the dust carried over by the combustion gases is held at a minimum. Even this minimum is too much to discharge into the air, therefore, an effective means of removal must be provided. It is a fact that a force must be applied to the dust particles to remove them from the gas stream. This may be gravitational, inertial, electrostatic, magnetic, or mechanical. The use of some of these means of applying force are precluded by the temperature or chemical characteristics of the transporting gas or the size of the particles. For most economical cleaning, the solid impurities or the dust should be concentrated in as small a volume of gas as possible, and the temperature reduced low enough to permit use of reasonably priced control equipment.

The volume of the gases may be reduced by several methods. First, of course, the combustion air should be held at the minimum necessary for complete combustion and leakage of air should be prevented. The most desirable means of cooling the gases is by abstracting the heat without mixing any fluid with them. Second, a method often used, is cooling the gas by using its heat to evaporate water introduced into the gas stream by spraying. This method will result in an increase in volume of about 50% over that if the heat is extracted by a transfer method. The final method for cooling is by diluting with ambient air. This will increase the resultant volume by 300%. Since dust control equipment is rated on a volumetric basis, it is apparent that the savings made by these latter methods of cooling may be outweighed by an additional control capacity required because of the increased volume.

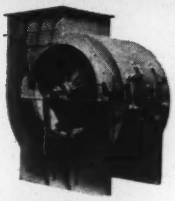
The earliest central incinerators either had no control equipment or depended on change in velocity in the secondary combustion chamber, the flue passages, perhaps the settling chamber and the base of the stack for removal of the dust. These methods are very ineffective and inefficient since the smaller particles are

not affected at all and those larger particles, which settle out through sheer weight, may be reentrained if the gas flow pattern is changed for any reason. A later development was the installation of baffles in a settling chamber. This had the advantage of producing sudden changes in gas flow direction and was more effective than the common settling chamber but still had the disadvantage of low efficiency and the reentrainment of particles when the flow pattern changed. Scrubbers have been, and are being successfully used in reducing the dust loadings of the discharged gases to a point acceptable to many jurisdictions. These have the disadvantage that they are subject to corrosion and use large quantities of water. High efficiency cyclones also may be used and should be effective in removing dust above 10μ in size, provided the gas is properly cooled and contains no suspended water particles. Electrostatic precipitators should be used in areas where the very fine dust which passes the simpler type of collectors, is objectionable.

Dispersal. The normal products of combustion and the dust which passes even the most efficient collector must be discharged into the air. This should be done so as to obtain the most rapid dispersal. Power plant designers have found that normally the stack outlet should be at least $2^1/_2$ times the height of the building itself. Unusual topographical features may require modifications in the height of the stack. Indeed, because of this fact many utilities conduct wind tunnel tests on models of their plant and the area in which they propose to erect it. The results of the tests may cause modifications in the proposed proportions of the building and stack. Dispersal of incinerator stack effluent without nuisance is just as important as with power plant stack effluent and merits the same tests and care in design.

Collateral Advantages of Control

Capital Savings. Effective control designed into an incineration plant and incorporating the three elements of prevention, removal, and dispersal cited above may decrease the capital investment required for the building, furnaces, breechings, and the stack, as well as, for the ash handling equipment. Increasing the temperature in the furnaces will result in a smaller furnace for the same capacity. Conditioning the gases by cooling them and economy in the use of excess air will decrease the size of the breechings, the control equipment, and the stacks. Decrease in the size of these elements of the plant will decrease the size of the enveloping building, so that the savings in capital cost will be cumulative. It must, of course, be considered that



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effective control equipment will be more costly than less efficient equipment but these costs may be largely outweighed by the savings made by reduction in size of the furnace, etc.

Income Producing Potential. Refuse is a fuel having a heating value of approximately 6000 BTU/lb of combustibles or about 1/4 the heating value of coal. The heat generated in burning this refuse may be utilized to generate steam or to heat water and in this form the heat will serve to generate electricity to supply heat to buildings or for other processes. The incinerator at Atlanta, Georgia uses the heat for the generation of steam which is sold to the utility. A new incinerator for the township of Oyster Bay in Long Island generates steam which is used for providing all power needed for the operation of the incinerator. The Louisville, Kentucky plant was planned to provide steam for drying sludge from the sewage treatment plant—the sludge to be used for fertilizer. It was a common practice in England, some years ago, to generate steam in the incinerator to provide power for the electric trains in the town. Certainly, it is abhorent to an engineer to see useful heat wasted and the resourceful American engineer can find uses for this steam particularly in heavily populated centers.

Other Sources of Air Pollution at Incinerator Plants

The heavy truck traffic required to bring refuse to and take residue from incinerators may cause air pollution by stirring up dust from the roads and streets used. This can be and should be controlled by keeping the paved streets as clean as possible and by frequent oiling of the unpaved roads or streets. Care should be taken also in handling the incinerator residue and particularly the fly ash removed from the control equipment. These should always be wetted down and when dumped the fly ash should be covered with material such as sand or earth fill. The fly ash is extremely fine and if not so covered may be the cause of a secondary nuisance.

The areas within the incinerator where the trucks are dumped, and in most cases the refuse rehandled, are serious sources of air pollution as well as a cause of poor working conditions for employees and increased maintenance on machinery. Every reasonable means, therefore, should be used to control this dust by exhaust systems taking it to dust collectors and frequent cleaning of the surfaces on which dust collects, not by sweeping but preferably by vacuum cleaning.

Need for Testing and Research

Millions of dollars of public money are spent every year for the construction of central incinerators. Too often the public pays again in damage to its property and person, if the resulting incinerator emits air pollution due to incorrect design, lack of control equipment, or poor operation. It is time to tackle the problems involved with promptness and vigor to arrive at a quick and correct solution. The design parameters and operating methods found by tests and research to result in "the reduction of refuse by burning without nuisance to a nonputrescible residue," should then be determined and widely disseminated to engineers and public officials throughout the country.

Test Methods. It seems to me that the first step should be taken by the American Society of Mechanical Engineers. Incineration is a combustion process which is in the field encompassed by our activities. Furthermore, we already have issued power test codes determining dust concentrations in a gas stream, dust separating apparatus, and many others. Testing incinerators, because of the high gas temperatures encountered, requires modifications of the test code, and too often the method used gives erroneous results on a basis which makes comparison or even evaluations of performance impossible.

A bridge if it is poorly maintained, improperly designed or overloaded will fall and its failure will be apparent to all. An incinerator, on the other hand, may be a failure from the day it is put into operation, either because it does not reduce the designed quantity of refuse to a nonputrescible residue, or does it only at the cost of creating a nuisance from excessive dust and noxious gases emitted. It is essential therefore that performance standards and test procedures be completed and promulgated and the ASME should do it promptly.

Testing. Incinerators built with public funds should be tested before acceptance by an impartial, qualified engineer or test organization whose only objective is to report the truth. He should be retained directly by the governmental jurisdiction paying the cost of the project. Therefore, the original specifications should state the tonnage capacity, the completeness of the refuse reduction required, and the allowable emissions which must be obtained simultaneously.

Research. Incinerators are used in all sections of the country. Determining design parameters for effective and nuisance-free incineration is a major problem. The cost of obtaining the solution, therefore, is one for which public funds can properly be used. The national agencies best qualified for this research, are the Bureau of Mines and the U. S. Public Health Service, both of which have been doing some research on a small scale in limited phases of incineration. The millions in public money spent each year for central incinerators and the growing concern about air pollution warrant a prompt allocation of sufficient funds to do the necessary research tests and developments to solve the problem quickly.

Dissemination of Information. Results of tests and progress reports on research should be sent by mail as soon as possible directly to public officials and designers so that facts learned may be quickly used. Presentation of material at technical meetings and publication should follow promptly for a more complete distribution.

Tolerance Must be Deserved

Incinerators are necessary to dispose of the refuse generated in large communities. It is possible to design and operate them so that they may function without creating a nuisance or cause unnecessary air pollution. Incinerators so designed will eliminate the principal reason for public opposition to their location in the area where they may serve most effectively and in time, I believe, will lessen and may eliminate the opposition of the public to the location of an incinerator near where they live.

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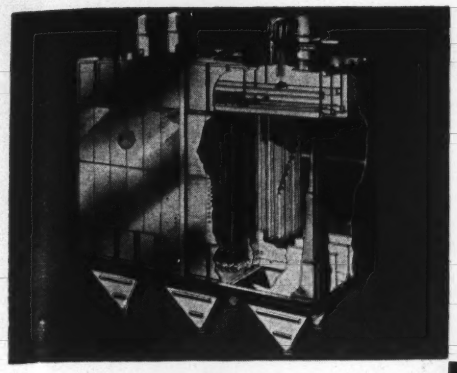

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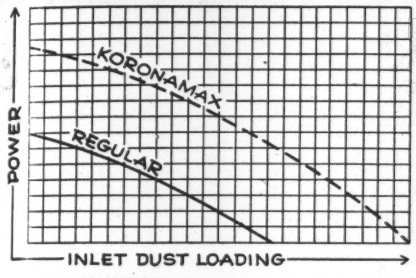

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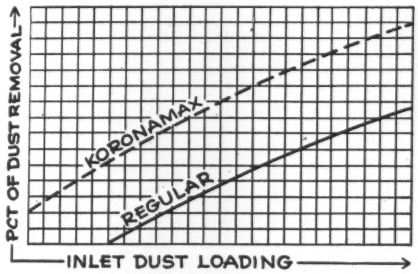

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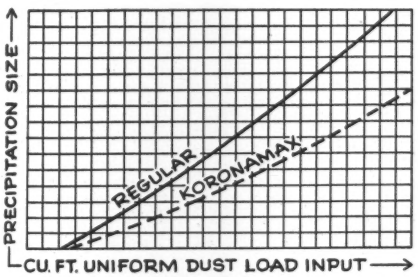

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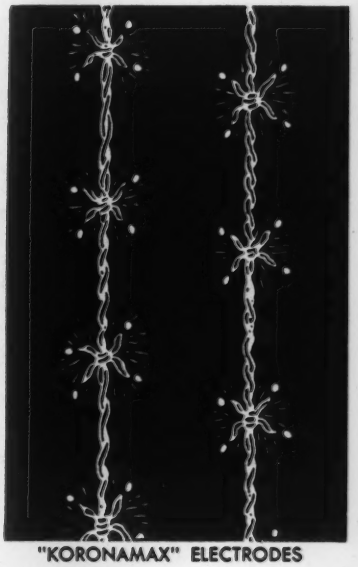

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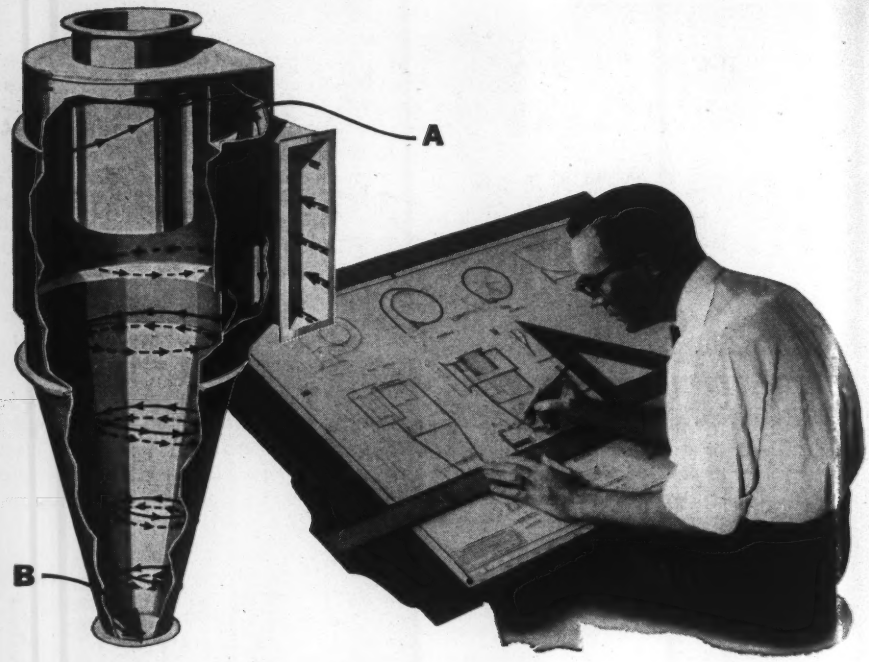

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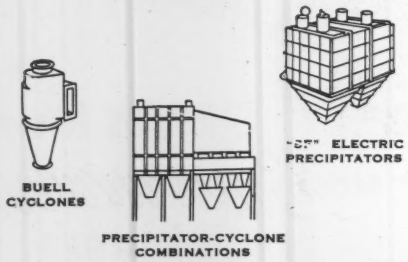

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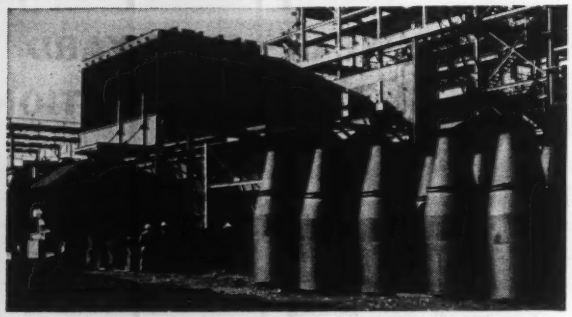

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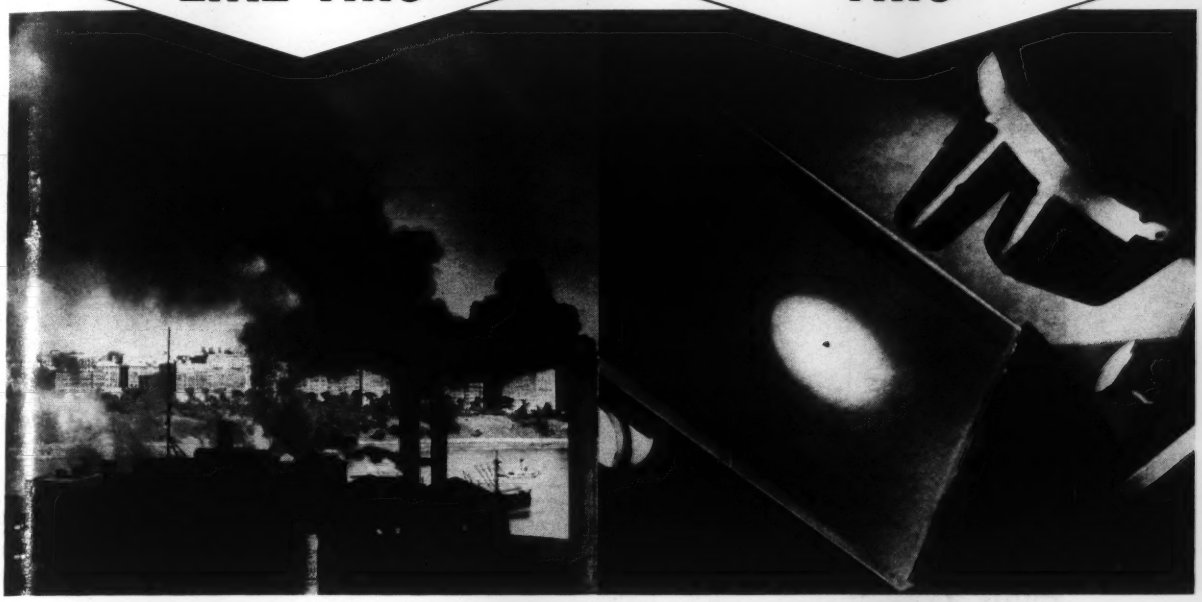
IF YOUR SAMPLE IS A TRACE

LIKE THIS or **THIS**



These accessories will multiply the range of your P-E Model 21 Spectrophotometer

In air pollution studies, trace gas or liquid analyses, biomedical micro-sampling . . . these Perkin-Elmer* accessories enable you to take full advantage of the remarkable range and sensitivity of your P-E Model 21 Spectrophotometer. In effect, they add—at moderate cost—a large factor of analytical capability.

The P-E **Long Path Cell** in conjunction with the P-E **Ordinate Scale Expansion System** can increase the effective path length up to 800 meters, making it possible to detect gases in the parts per **billion** range! The P-E **Ultra-Micro Sampling System** gives a 6x energy concentration of the infrared sample beam, permitting the analysis of samples weighing as little as 0.1μgm in a KBr disc as small as 0.5mm in diameter.

Perkin-Elmer has pioneered practically all present sampling accessories for infrared spectrophotometers. The accessories shown here represent the most recent additions to our accessory line.

The range and convenience of the Model 21 may be still further extended with many other P-E sampling and recording attachments. We'll send you complete product data on all of these. Also available: an informative technical paper, "Infrared Microsampling in Bio-Medical Investigations," by W. B. Mason of the University of Rochester, and a reprint of a paper on ordinate scale expansion by Vincent J. Coates and Robert Anacreon of the Perkin-Elmer Corporation. Just write: Perkin-Elmer Corporation, 795 Main Avenue, Norwalk, Conn.

All prices subject to change without notice.

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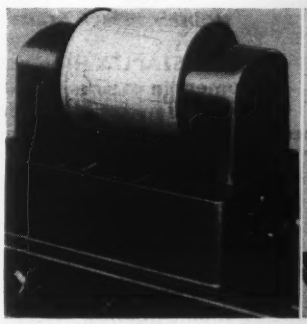
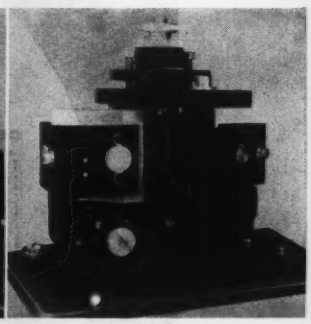
INSTRUMENT DIVISION

Perkin-Elmer *Corporation*

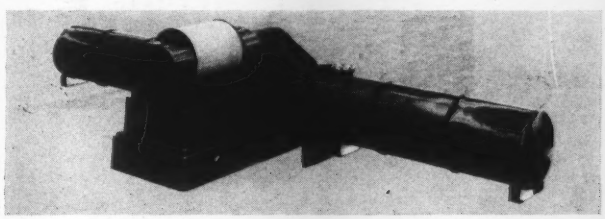
NORWALK, CONNECTICUT



Ordinate Scale Expansion System—Increases measurement sensitivity of Model 21, thereby providing a real gain in the ability to perform trace analysis. Permits precise measurement of weak absorption bands or small absorption differences at any point in the transmittance range.



Ultra-Micro KBr Sampling System—An all-reflecting optical system for concentrating the sample beam. Maintains high energy levels when analyzing extremely small samples. Price: $1,450. Ultra-Micro KBr Die for pressing 0.5 and 1.5mm KBr discs, $315.



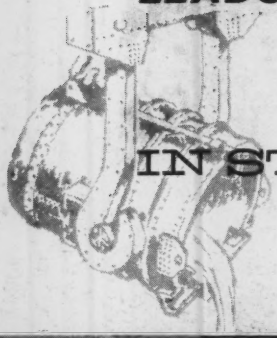
Twin 40-meter Long Path Cells—Effective path lengths from 4 to 40 meters. Pressure range: 50 microns Hg to 100 psig. With scale expansion system of Model 21, path length equivalent to 800 meters can be obtained. Price: $5,000.

In Industry After Industry...

WESTERN

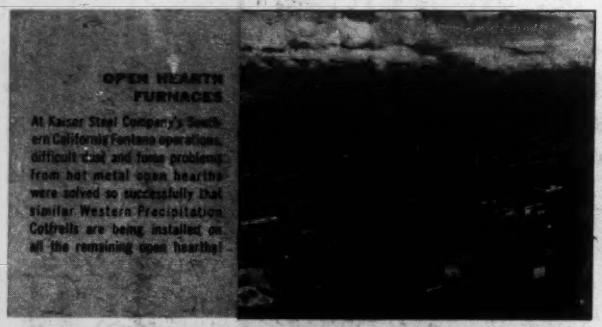
PRECIPITATION

LEADS IN DUST, FUME AND FLY ASH CONTROL!



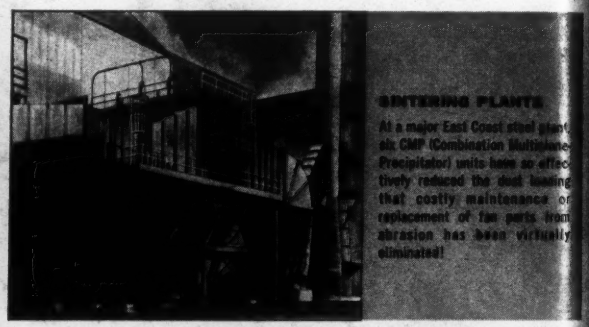
IN STEEL, *for example...*

as in power, cement, smelting and other industries—Western Precipitation is setting new standards of achievement in the control of dust, fume and fly ash. These Steel installations are typical...



OPEN HEARTH FURNACES

At Kaiser Steel Company's Southern California Fontana operations, difficult dust and fume problems from hot metal open hearths were solved so successfully that similar Western Precipitation Cottrells are being installed on all the remaining open hearths!

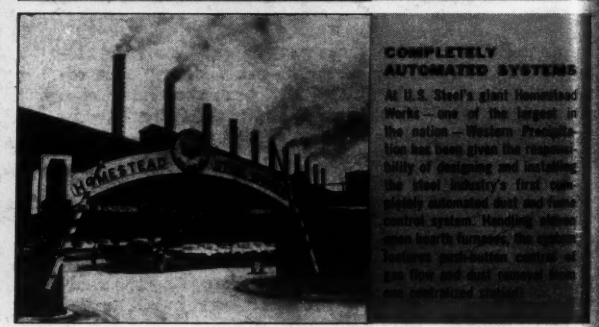


SINTERING PLANTS

At a major East Coast steel plant six CMP (Combination Multiclone-Precipitator) units have so effectively reduced the dust loading that costly maintenance or replacement of fan parts from abrasion has been virtually eliminated!

ELECTRIC FURNACES

At Jones & Laughlin's Otis Works in Ohio, Western Precipitation has been given the job of installing a complete "turn-key" dust control system on 3 of J & L's electric furnaces. In addition to Cottrell Precipitators, Western Precipitation will install Rotoclone fans, fume conditioning towers, ducts, stack and instrumentation—a complete "turn-key" installation.



COMPLETELY AUTOMATED SYSTEMS

At U.S. Steel's giant Homestead Works—one of the largest in the nation—Western Precipitation has been given the responsibility of designing and installing the steel industry's first completely automated dust and fume control system. Handling eleven open hearth furnaces, the system features push-button control of gas flow and dust removal from one centralized station.

Whether your gas cleaning problem calls for Electrical precipitation (COTTRELL)... Mechanical collection (MULTICLONE)... Combination Electrical-Mechanical methods (CMP)... Filter collectors (THERM-O-FLEX and DUALAIRE) or Scrubbers (TURBULAIRE-DOYLE), Western Precipitation is the only organization that designs, engineers and installs ALL the major types of gas cleaning equipment. Therefore, you get a completely unbiased recommendation from Western Precipitation—a recommendation backed by over a half-century of leadership in this highly-technical field!

These unequalled facilities are ready to serve you throughout the United States, Canada and the free world on a complete "turn-key" basis—or for any portion of a collection job. Write, wire or phone our nearest office.

G-121

COTTRELL Electrical Precipitators
MULTICLONE Mechanical Collectors
CMP Combination Units
DUALAIRE Jet-Cleaned Filters
THERM-O-FLEX Hi-Temp Filters
TURBULAIRE-DOYLE Scrubbers
HOLO-FLITE Processors
HI-TURBIANT Heaters

WESTERN

PRECIPITATION

CORPORATION

Engineers and Constructors of Equipment for Collection of Suspended Material from Gases . . . and Equipment for the Process Industries

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Representatives in all principal cities

Precipitation Company of Canada Ltd., 8285 Mountain Sights Avenue, Montreal 9